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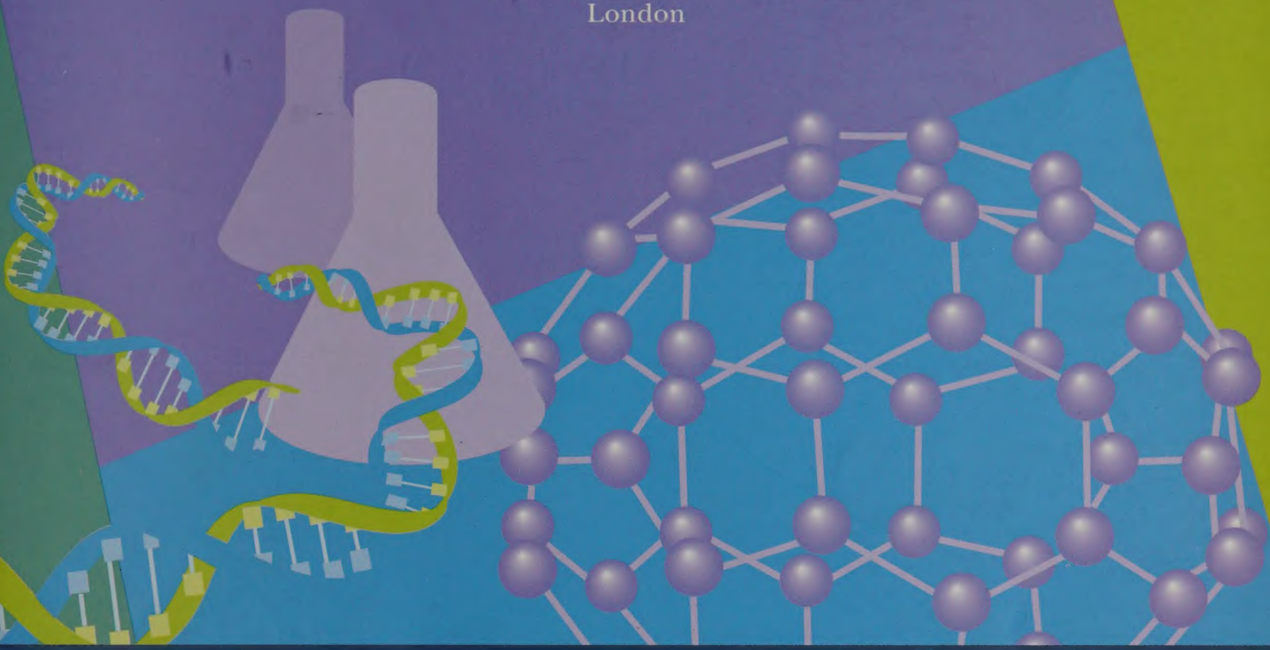

Science, Engineering & Technology in Britain

A

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Front cover: An inspector makes a final inspection inside one of the latest power generators before it is exported by the British manufacturer, Parsons Power Generation Systems, part of the Rolls-Royce Industrial Group.

'Britain' is used informally in this booklet to mean the United Kingdom of Great Britain and Northern Ireland. 'Great Britain' comprises England, Wales and Scotland.

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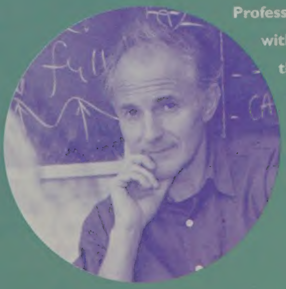
Introduction

Science, engineering and technology affect our everyday lives in a multitude of ways. Their role is fundamental to the prosperity of a leading industrial and trading nation such as Britain, with the ability to compete successfully in today's highly competitive world markets depending increasingly on the production and bringing to market of innovative high-technology goods and services. As well as playing a vital part in wealth creation, science, engineering and technology can enhance the quality of life by helping to bring about improvements in health, employment, the environment, transport and other areas of life.

Britain has a long history of excellence in scientific research and development (R&D). Its strong record of achievement is in many ways unsurpassed and prevails to the present day. There are few branches of science, engineering and technology in which the scientific community in Britain has not excelled, winning more Nobel Prizes for Science – over 70 – than any country except the United States. Its scientists are second only to those of the United States in the production of papers and achievement of citations. With only 1 per cent of the world's population, Britain conducts 5.5 per cent of world research.

Around £14,000 million is spent each year on R&D in Britain, with the Government being responsible for about a third of this. Including expenditure on technology transfer and postgraduate training, government spending amounts to over £6,000 million annually.

International collaboration has long been a tradition in science and is ever more important today, with many British research teams engaged in major programmes in partnership with their overseas counterparts.



Professor Sir Harold Kroto of Sussex University shared the 1996 Nobel Chemistry prize with two US scientists for discovering the fullerene molecule. The three confirmed the structure of fullerene, which has 60 carbon atoms arranged in a symmetrical cage, during an 11-day experiment in 1985. There is now a long list of potential uses for fullerene and for materials derived from it: high-temperature superconductors, drugs, ultra-strong fibres, super-slippery lubricants, lightweight magnets and electronic superconductors.

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Government policy and organisation

Introduction

Science, engineering and technology are vital components in Britain's intellectual, cultural and industrial heritage. The new Government, which came into office in May 1997, has underlined its public commitment to the science base, and stressed its role in improving the competitiveness of the United Kingdom and the quality of life of its people.

The Government has indicated some of the key challenges for the future:

- the need to develop a strong partnership between business, the scientific community and government in order to maximise the benefits flowing from scientific and technological developments
- the need to maximise the potential of the scientific world's most important resource – its people
- the need to promote the public understanding of the importance of science in ensuring that social, environmental and economic objectives are met.

Set out below, and in the subsequent chapters, are examples of the programmes and administrative structures which are being used to address these objectives.

Science and technology issues as a whole are the responsibility of the President of the Board of Trade, who is supported by the Office of Science and Technology (OST), part of the Department of Trade and Industry (DTI). The OST, headed by the Government's Chief Scientific Adviser, provides a central focus for the development of government policy on science and technology, both nationally and internationally. It encourages government departments engaged in activities concerning science, engineering and technology to liaise with each other where programmes straddle more than one department. The OST also co-ordinates policy-making in areas in which no single department takes the lead. Government departments' priorities and projected expenditure are outlined in the annual *Forward Look of Government-funded Science, Engineering and Technology*.

Seafish Aquaculture, a division of the Sea Fish Industry Authority, is pioneering techniques for cultivating fish and shellfish in aquaculture units at Ardtoe, Argyll, Scotland.

Scientists at Cambridge University have used a new type of optical telescope, the Cambridge Optical Aperture Synthesis Telescope, to resolve the finest details yet seen in any image of a star system. The instrument is so powerful that its ability to discern detail is comparable to reading a car's number plate from 1,000 kilometres.

A new centre dedicated to helping Scotland's thriving semiconductor industry has opened at the University of Edinburgh. The Microelectronics and Analysis Centre aims to provide advanced facilities for problem solving in the design and manufacture of integrated circuits.

The Foresight Programme (see p. 18) is intended to help ensure that future spending on research will be more closely related to meeting Britain's needs, enhancing the capacity for wealth creation and improving the quality of life of people in Britain.

The Government is committed to raising public understanding and awareness of science, engineering and technology and of the vital role that they play in boosting competitiveness and improving the quality of life. A special team within the OST promotes greater public understanding. Its annual budget of £1.25 million finances a number of activities, including the National Week of Science, Engineering and Technology (see p. 16). The team also provides grants through the Committee on the Public Understanding of Science and the OST's Women's Development Unit (see p. 17), and supports the Year of Engineering Success campaign being undertaken throughout 1997.

The OST has specific responsibility for the Science Budget and for seven government-financed Research Councils (see pp. 7-11). They cover engineering and physical sciences, particle physics and astronomy, biotechnology and biological sciences, biomedical and health sciences, the natural environment and economics and social science. The Council for the Central Laboratory of the Research Councils is responsible for the provision of facilities and expertise in support of many of these areas.

OST funding provides assistance for research, through the Research Councils, in the following ways:

- awarding grants and contracts to universities and other higher education establishments and to research units
- funding Research Council establishments
- supporting postgraduate study
- maintaining national research facilities
- subscribing to international research facilities and scientific organisations.

As the department responsible for government-wide research projects, the OST administers the LINK scheme, which encourages collaboration between academic and industrial research (see p. 19).

Research in higher education institutions

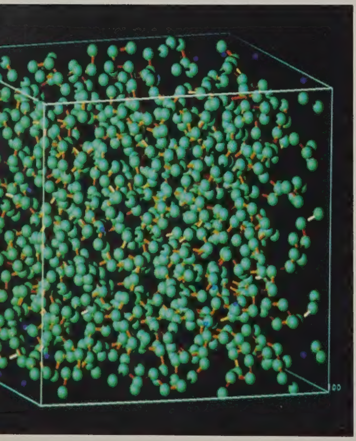
Universities carry out most of Britain's long-term strategic and basic research. The higher education funding councils in England, Scotland and Wales provide the main general funds – totalling £1,026 million in 1997–98 – to support research in universities and other higher education institutions in Great Britain. These funds meet the salaries of academic staff, who usually have teaching as well as research duties, and contribute to the infrastructure for research. Research in Northern Ireland higher education institutions is financed directly by central government.

The other main channels of support for scientific research in higher education institutions are Research Councils, industry, charities, government departments and the European Union (EU). Institutions are expected to recover the full cost of commissioned research.

The high quality of research in higher education institutions, and their marketing skills, has enabled them to attract funding from a large range of external sources, especially in contract income from industry and charities.

In 1996 the higher education funding councils published the results of the fourth Research Assessment Exercise, which provide a comparative analysis of the quality of research being undertaken in all university departments across the range of subjects.

Research and development expenditure



To improve understanding of how substances behave during chemical reactions, the Daresbury Laboratory, in Cheshire, northern England, is using lasers and synchrotron radiation to create 3-D images of molecular arrangements. This has implications for the causes of urban smogs and the behaviour of ozone in the upper atmosphere.

Introduction

Total expenditure in Britain on scientific research and development in 1995 was £14,300 million, 2 per cent of gross domestic product (GDP). About 48 per cent of the funding was provided by industry and around 33 per cent by government. Significant contributions were made by private endowments, trusts and charities.

In international comparisons among the G7 countries Britain occupies a middle-ranking position in terms of R&D expenditure as a proportion of GDP (see Table 1). When this is restricted to government-funded R&D Britain again ranks in the middle. The main categories of expenditure, by socio-economic objective, are shown in Table 2.

Industrial R&D

Total spending on R&D in industry amounted to £9,379 million in 1995. Of this, British industry's own contribution was 69 per cent, with 12 per cent from government and the rest from overseas. Since the ending of the Cold War, there has been a marked shift in the balance between civil and defence-related R&D, reflected, for example, in a reduction in real terms in aerospace R&D.

Many companies in major industries finance their own research and run their own laboratories. Industry also funds university research and finances contract research at government establishments and other research and technology organisations. Smaller companies commission research from industrial research organisations.

The chemistry and biotechnology-based sectors – chemicals, pharmaceuticals and healthcare – account for 19 per cent of all industrial R&D spending. The three companies with the largest investment in R&D – Glaxo Wellcome, SmithKline Beecham and Zeneca – are in these sectors.

Government-funded R&D

Government finance for R&D goes to research establishments, higher education institutions and private industry, as well as collaborative research programmes. Total net government expenditure on science and technology (both civil and defence) in 1997–98 is £6,306 million, of which £3,807 million will be devoted to civil science. The Science Budget (primarily Research Council expenditure) totals £1,330 million for 1997–98. Government funding for the science and engineering base (basic and strategic research financed through the Research Councils and universities) has increased by 10 per cent in real terms in the past ten years.

In 1997–98 the Department of Trade and Industry (DTI)'s net planned expenditure on science and technology is estimated at £363 million, covering innovation and technology, aeronautics, space and nuclear and non-nuclear energy. Its overall aim is to help companies

Table 1: International comparison of gross expenditure on R&D 1995

	Per cent of GDP
Britain	**2.05**
Canada	**1.60**
France	**2.34**
Germany	**2.28**
Italy	**1.14**
Japan	**2.78**
United States	**2.58**

Sources: Office for National Statistics and Organisation for Economic Co-operation and Development Databank (March 1997).

Table 2: Government funding of R&D in Britain by socio-economic objective 1995–96

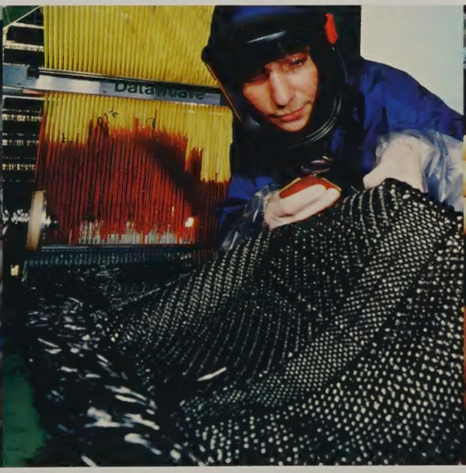
	Per cent
Defence	37.0
Advancement of knowledge	29.4
Health	13.4
Agriculture, forestry and fishing	5.0
Industrial development	2.9
Civil space	2.7
Social development and services	2.4
Environmental protection	2.3
Earth and atmosphere	1.9
Infrastructure	1.7
Energy	0.9
Other	0.4

Source: *Science, Engineering and Technology Statistics 1997.*

to compete more effectively in global markets through improved innovation performance. It seeks to achieve this, in particular, by helping to improve the climate for business innovation, by encouraging industry to invest more in R&D, and by helping to develop partnerships between the academic base and industrial sectors. The DTI's innovation and technology programmes, therefore, concentrate on the transfer of technology, knowledge and techniques, the spread of management best practice, the promotion of innovation and, in certain areas, the development of technology, particularly by small and medium-sized enterprises and by collaborative partnerships between industry and the science base.

The Ministry of Defence has the largest government research budget, £2,133 million for 1997–98, of which about £572 million is for medium- and long-term applied research relevant to military needs. The Defence Evaluation and Research Agency (DERA) is the biggest single employer of scientists in Britain. It has set up four dual-use technology centres, in subjects ranging from structural materials to high-performance computing, to enhance the degree of collaboration between the DERA, industry and the academic science base. The DERA works closely with industry in order to see that

British scientists at London's Imperial College of Science, Technology and Medicine have developed the 'active constrained robot', or Acrobot, to help surgeons perform delicate knee operations quickly and safely. Now on trial at Guy's Hospital, London, Acrobot can be programmed to cut within a precisely defined area, corresponding to a scan of the patient's knee.



New developments in textile technology and engineering are now being brought together at the Engineering Composites Research Centre at the University of Ulster, Northern Ireland. Here, a technician at the Centre examines carbon fibres manufactured on its half-metre loom.

Oxford University scientist Dr Joshua Silver has invented low-cost spectacles in which the wearers themselves use syringes to adjust the fluid-filled lenses. Recent prototype trials with people needing near-sight correction in Ghana, supported by the World Health Organisation and Britain's Department for International Development, have had dramatic results.

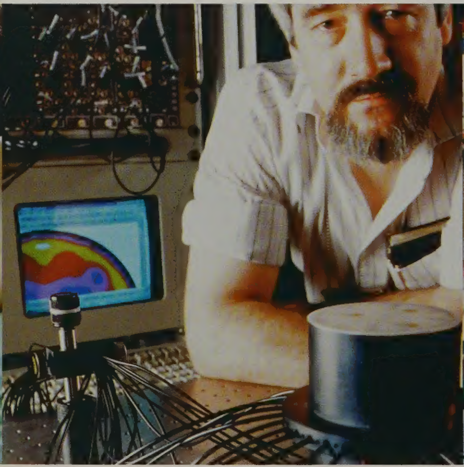
scientific and technological advances are taken forward into development and production. This technology transfer has also led to important 'spin offs' into civil markets, in fields ranging from new materials and electronic devices to advanced aerodynamics.

The Department for International Development (DFID) supports R&D on topics relevant to developing nations, as well as the states of Eastern Europe and Central Asia; for 1997–98 it has a research budget of £79 million. The DFID works in partnership with the governments of these countries and international organisations like the European Union (EU) and the United Nations. The R&D programme comprises five main components, covering: renewable natural resources and environment; engineering-related sectors (water and sanitation, energy efficiency and geoscience, urbanisation and transport); health and population; economic and social development; and education.

Funding by medical research charities and others

Medical research charities are a major source of funds for biomedical research in Britain. Their combined contribution in 1996–97 was around £342 million. They range from the Wellcome Trust, the world's largest medical research charity, and the Imperial Cancer Research Fund, Europe's leading independent cancer research institute, to small charities dedicated to raising funds for work in very rare disorders.

A technique called photodynamic therapy (PDT) has been developed by medical researchers at the University College of London to help treat patients with oral cancer. Instead of using a scalpel to cut out tumours, doctors can give patients a drug that makes the diseased tissue ultra-sensitive to light, and then destroy the cancerous cells by laser beam.



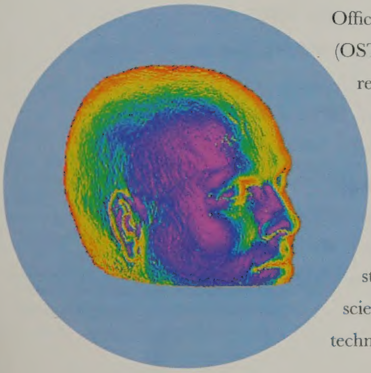
A scientist at the Defence Evaluation and Research Agency, Farnborough, southern England, demonstrates the principle of the ion thruster, a propulsion system designed to reduce dramatically the amount of fuel required for long satellite missions. The DERA's T5 thruster will be used on the European Space Agency's Artemis spacecraft, scheduled for launch in 1997.

The diagnosis of breast cancer and brain damage will be improved by a bedside near-infra–red (NIR) light imager being developed at University College London. The picture shows Professor David Delpy, the research team leader, with a prototype machine about to undergo clinical trials. The great advantage of NIR-imaging over using X-rays is that it is harmless and can be used continuously.

Research Councils

Introduction

The Research Councils support research, study and training in universities and other higher education institutions, through their own institutes, and international research centres. Each Council is an autonomous body, with members of its governing council drawn from the universities, professions, industry and government. In addition to funding from the Office of Science and Technology (OST), the Research Councils receive income for research commissioned by government departments and from the private sector. They provide awards to about 15,000 postgraduate students in science, social sciences, engineering and technology.



A magnetic resonance image produced by Professor Chris Morfey at Southampton University as part of his Engineering and Physical Sciences Research Council studies into head injuries caused by road accidents. His research should lead to improved designs for crash helmets and vehicles.

Engineering and Physical Sciences Research Council (EPSRC)

The EPSRC is the biggest of the Research Councils, with a budget of £386 million for 1997–98. Its main aims are to develop and sustain basic, strategic and applied research in engineering and the physical sciences and to maintain postgraduate skills. The EPSRC programme is delivered through eight areas – three in science (physics, chemistry and mathematics), two in generic technologies (information technology and materials) and three in engineering (general engineering, engineering for manufacturing and engineering for infrastructure, the environment and healthcare).

There is also a 'cross-programme' area which deals with research facilities, high performance computing and a range of other cross-programme schemes.

Particle Physics and Astronomy Research Council (PPARC)

The main task of the PPARC is to sustain and develop Britain's long tradition of excellence in research into fundamental physical processes. It maintains four research establishments: the Royal Greenwich Observatory at Cambridge, the Royal Observatory at Edinburgh and overseas observatories on La Palma in the Canary Islands and on Hawaii. It is a major source of funding for many leading university physics departments in Britain.

The PPARC supports research in three main areas:

- particle physics – theoretical and experimental research into elementary particles and the fundamental forces of nature
- astronomy (including astrophysics and cosmology) – studying the origin, structure and evolution of the universe, and the life cycle and properties of stars and galaxies
- planetary science (including solar terrestrial physics) – studying the origin and evolution of the solar system and the influence of the Sun on planetary bodies, particularly earth.

Biotechnology and Biological Sciences Research Council (BBSRC)

The BBSRC supports basic, strategic and applied research and postgraduate training related to the understanding and exploitation of biological systems. It aims to advance knowledge and technology, and to provide trained scientists and engineers, for the benefit of the agriculture, bioprocessing, chemical, food, healthcare, pharmaceutical and other biotechnology-related industries. It also provides advice, disseminates knowledge and promotes public understanding in the fields of biotechnology and the biological sciences.

The BBSRC operates programmes both in fundamental science and strategic research in seven areas:

- biomolecular sciences
- biochemistry and cell biology
- genes and developmental biology
- animal sciences
- plant and microbial sciences – including the study of the interactions between plants and their pests and pathogens, control of pests and diseases and soil science
- engineering and biological systems
- agri-food – including animal welfare, technologies for crop and livestock improvement, agriculture in the environment, raw material quality, food manufacturing, diet and health and microbiological food safety and preservation.

Research projects are supported in eight institutes sponsored by the BBSRC and in universities through responsive mode project grants, initiatives and co-ordinated programmes, programme grants, equipment grants, interdisciplinary research centres and institute rolling grants.

In total the BBSRC supports 8,000 scientists, technical support workers, research students and fellows.

Medical Research Council (MRC)

The MRC supports basic, strategic and applied research and postgraduate training in biomedical science and other relevant areas with the aim of maintaining and improving human health. It seeks to advance knowledge and technology and to provide trained researchers to meet the needs of users, including providers of healthcare, and the pharmaceutical, biotechnology, food, medical instrumentation and other biomedical-related industries.

About half of the MRC's research expenditure takes the form of grant support to universities and medical schools. The other half goes on its own establishments, which are made up of over 40 research units, most at universities, and two large institutes – the National Institute for Medical Research in London and the Laboratory of Molecular Biology in Cambridge; it also runs the Clinical Sciences Centre at the Royal Postgraduate Medical School, London. The Council's Technology Transfer Group plays a key role in setting up and facilitating agreements relating to the use of MRC intellectual property rights.

The MRC's research activities cover the following broad areas:

- macromolecules, cells and developmental biology
- genetic blueprint and health
- environment and defences
- infections, immunity and inflammation; this area includes the MRC's significant

A researcher at the Advanced Centre for Biochemical Engineering, University College London, setting up fermentation vessels as part of a scale-up study of the methods for the synthesis of novel microbial bi-products

research programme in HIV/AIDS
- neurosciences and mental health
- organ systems and cancer
- health services and public health.

Natural Environment Research Council (NERC)

Many NERC programmes have important implications for sustainable development, environmental protection and issues concerning the quality of life. The NERC spends most of its Science Budget allocation in the following areas:

- understanding and protecting biodiversity;
- environmental risks and hazards
- global change
- natural resources – management and exploitation of land, water and the coastal zone
- waste management, bioremediation (biological treatment of pollution) and land restoration
- pollution of air, land, sea and freshwater in relation to environmental and human health.

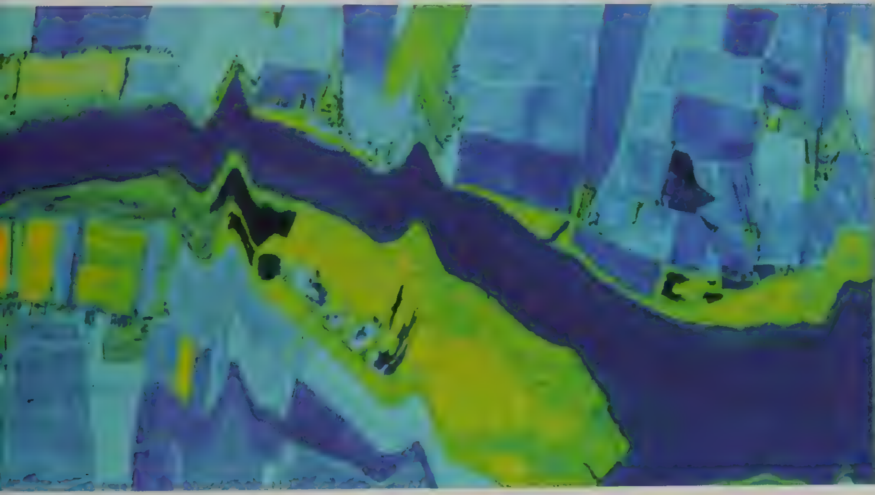
The Council supports research in its own and other research establishments as well as research and training in universities. It also provides facilities for use by the environmental science community, including a marine research fleet. The NERC establishments include the British Geological Survey, the British Antarctic Survey, the Centre for Coastal and Marine Sciences and the Centre for Ecology and Hydrology, together with university-based units.

The Southampton Oceanography Centre, a joint venture with Southampton University, was opened in 1996. It is a national centre for research, training and support in oceanography, geology and aspects of marine technology and engineering.

Economic and Social Research Council (ESRC)

The ESRC supports research and training to enhance Britain's economic competitiveness, the quality of life and the effectiveness of public services and policy. All research funded by the ESRC is conducted in higher education institutions or independent research institutes. The Council has nine priority themes:

- economic performance and development
- environment and sustainability
- globalisation, regions and emerging markets
- governance and regulation
- human communication and the social shaping of technology



Simulated true colour image acquired by the Compact Airborne Spectral Imager (CASI) of the River Ouse, in the north-east of England. NERC scientists at the Centre for Ecology and Hydrology use such images to monitor the movements of pollutants that bind to sediment particles.

The *Charles Darwin*, one of the research vessels used by the Southampton Oceanography Centre.

- innovation, organisations and business processes
- knowledge and skill
- lifespan, lifestyles and health
- social integration and exclusion.

The Council has already made significant investments in the area of innovation, organisations and business processes, launching three new centres in 1996–97:

- the Centre for Research on Innovation and Competition, Manchester
- the Centre for Organisation and Innovation at the University of Sheffield
- the Complex Product Systems Innovation Research Centre at the Universities of Sussex and Brighton.

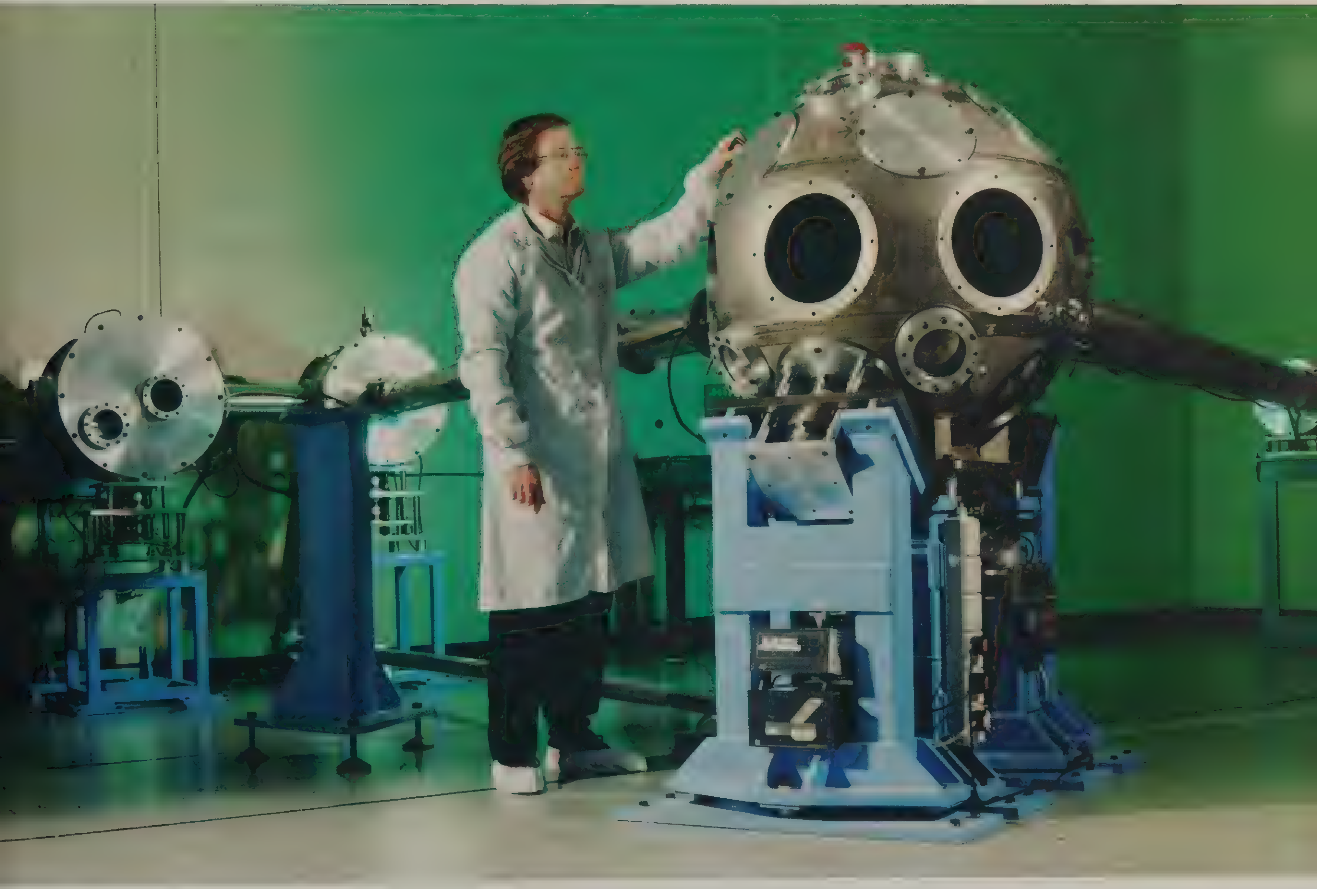
Council for the Central Laboratory of the Research Councils (CCLRC)

The CCLRC promotes scientific and engineering research by providing facilities and technical expertise to meet the needs of the other Research Councils and their users. Its R&D budget for 1996–97 is £104 million, of which £82 million comes through agreements with the other Research Councils and the rest from contracts and agreements with overseas countries, the European Union (EU) and other industries and organisations. It is responsible for three research establishments:

This 25-metre dish at the Chilbolton Observatory, near Andover, southern England, supports the experimental programme of the Radio Communications Research Unit (RCRU), based at the Rutherford Appleton Laboratory.

- the Rutherford Appleton Laboratory in Oxfordshire
- the Daresbury Laboratory in Cheshire, and
- the Chilbolton Observatory in Hampshire.

These centres provide facilities too large or complex to be housed by individual academic institutions and also undertake contract research. Among the facilities are ISIS, the world's leading source of pulsed neutrons and muons (see p. 25), some of the world's brightest lasers and the United Kingdom Synchrotron Radiation Source (see p. 25), Britain's only source of synchrotron light (X-rays).



After 20 years of development, the Rutherford Appleton Laboratory has built the world's most powerful ultra-violet laser Known as Titania, the new machine can generate a power of up to 10 terawatts in a single pulse lasting only 300 femtoseconds Titania's krypton fluoride pulses can be delivered to users' experiments or focused on a target inside a chamber, as shown here

International collaboration

European Union (EU)

The EU runs a series of R&D framework programmes in several strategic sectors, with the aim of strengthening the scientific and technological base of European industry and supporting the development of EU policies more broadly.

The EU's Fourth Framework Programme for Research and Technological Development lasts from 1994 to 1998. It has a budget of about £11,000 million and provides funds for international collaborative research in fields such as the environment, energy, transport, life sciences, industrial materials and information technology.

Britain is a partner in 75 per cent of all projects within the Fourth Framework Programme.
It participates in more than 450 projects in the EU's Information Technology Programme.
The Training and Mobility of Researchers (TMR) programme promotes high-level training for researchers and their mobility across the EU. Britain is the most popular destination under the programme.

Negotiations are in progress on the make-up of the Fifth Framework Programme, due to commence in 1999. The British Government believes that it should be much more sharply focused on research relevant to improving competitiveness and supporting European policy-making.

Other international activities

Over 700 British organisations have taken part in the European High Technology Programme EUREKA, an industry-led scheme to encourage European co-operation in developing and producing advanced products and processes with worldwide sales potential. Britain currently participates in 300 EUREKA projects and held the chairmanship of EUREKA for 1996–97.

A US$50 million EUREKA project aims to improve competitiveness in the European constructional steelwork industry by, among other things, introducing computer-integrated design, manufacturing and management. The project is nearing completion after four years' collaborative work. CIMsteel's Integration Standards enable data to be transferred and managed electronically using a neutral software format. This allows each organisation in the design and construction 'chain' to employ the most appropriate software for its particular needs, significantly improving the speed and quality of the entire construction process. Taylor Woodrow, one of Britain's biggest construction groups, is Britain's lead partner in the joint venture.

The European Co-operation in the field of Science and Technical Research (COST) programme encourages co-operation in nationally-funded research activities across continental Europe, with participants from industry, academia and research laboratories. Transport, telecommunications and materials have traditionally been the largest areas supported. New areas include physics and chemistry, and the application of biotechnology to agriculture and forestry. Britain takes part in almost all of about 140 current COST actions.

Through the Particle Physics and Astronomy Research Council (PPARC), Britain contributes to international programmes/organisations, including the European Laboratory for Particle Physics (CERN) (see p. 24) and the European Space Agency. Contributions to the high-flux neutron source at the Institut Laue-Langevin and the European Synchrotron Radiation Facility, both in Grenoble, are paid by the Engineering and Physical Sciences Research Council (EPSRC).

Inward investment in R&D

Of all European patents registered to British-based firms in the early 1990s, more than 60 per cent were registered by overseas-owned concerns. Overseas companies with major R&D facilities in Britain include Du Pont, Ford, IBM, Johnson & Johnson, Nissan, Sharp, Sony and Daewoo. The high quality of research being undertaken at British universities and the close links between universities and industry backed by the Government are often cited by overseas companies as reasons for choosing to locate in Britain.

More than 100 Japanese companies have established research, development or design operations in Britain. South-east England in particular is home to a large number of overseas-owned research and development facilities specialising in, for example motor vehicles, avionics, defence equipment and information technology. Eight of the ten top software companies in the United States have major installations in the region. Microsoft, for example, has a new headquarters at Reading which will have capacity for 2,500 employees.

The Oxford Science Park, developed by Oxford University, houses Sharp Laboratories, whose facilities have recently doubled in size. The company quotes the opportunities for joint research with Oxford University and other local R&D organisations as one of the main reasons for locating its first overseas research laboratory there (see p. 14). Daewoo Cars, the South Korean manufacturer, opened a large new R&D operation at Worthing on the south coast to plan the next generation of cars for Europe. By mid-1996 it employed 870 people. A further 200 jobs have been generated with the firm's acquisition of an entire business park.

Overseas companies in Scotland's 'silicon glen', including IBM, NCR and Motorola, carry out substantial R&D work in electronics and computing.

Through the Medical Research Council (MRC), Britain participates in the European Molecular Biology Laboratory (EMBL), based in Heidelberg, Germany. The European Bioinformatics Institute, one of EMBL's outstations, is based at Hinxton, near Cambridge, and became fully operational in 1995. It provides up-to-date information on molecular biology and genome sequencing for researchers throughout Europe.

The MRC pays Britain's contribution to the Human Frontier Science Program, which supports international collaborative research into brain function and biological function

When the Japanese optics company Nikon required an infra-red interferometer to test the optical systems for the Japanese earth observation satellite, it turned to Sira, the British electro-optics specialist. Designed and built at the company's headquarters in southern England, the interferometer is shown here being tested.

A new type of re-configurable antenna has been developed for organisations including the European Space Agency at Queen Mary and Westfield College, part of the University of London. It will have applications in satellite communications, remote sensing spacecraft and radar. It is shown here being tested in the College's radio anechoic chamber, which simulates the radio conditions of space.

through molecular level approaches. It also pays Britain's subscription to the International Agency for Cancer Research and the European Molecular Biology Conference.

The Natural Environment Research Council (NERC) has a major involvement in international programmes of research into global change organised through the World Climate Research Programme and the International Geosphere-Biosphere Programme. It also supports Britain's subscription to the Ocean Drilling Program.

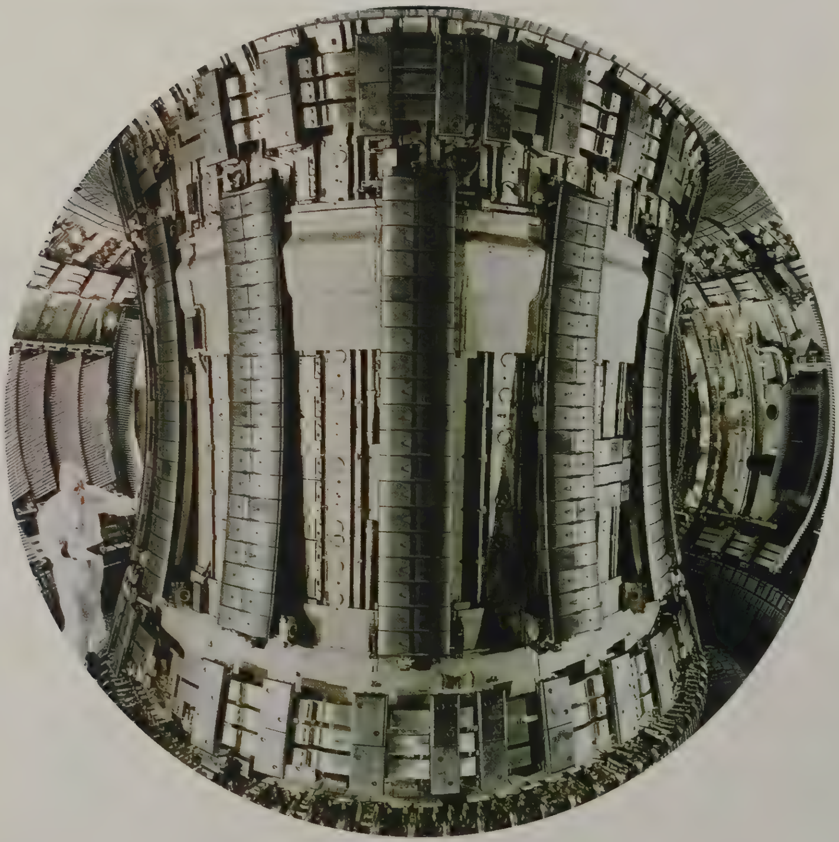
A collaboration between an Oxford University researcher and the Japanese electronics company Sharp has led to the production of a revolutionary new microwave oven that can choose the cooking times for different foods. Using techniques developed by Dr Lionel Tarassenko at Oxford University, the oven contains sensors which detect the characteristic steam 'signature' emitted by different foods when heated. It is Sharp's first product to be developed and manufactured outside Japan.

Britain is a member of the science and technology committees of international organisations such as the Organisation for Economic Co-operation and Development (OECD) and the North Atlantic Treaty Organisation (NATO), and of various specialised agencies of the United Nations. Among non-governmental organisations, the Research Councils, the Royal Society and the British Academy were founder members of the European Science Foundation in 1974.

The British Government also enters into bilateral agreements with other governments to encourage closer collaboration on science, engineering and technology. Such agreements were signed, for example, with Israel in 1994, South Africa in 1995 and with India and the Russian Federation in 1996.

The UK/South Africa Science and Technology Research Fund enables scientists from Britain and South Africa to collaborate on research projects in: biomedicine; agriculture and biotechnology; and environmental protection and utilisation of natural resources. Funded projects include: improvement of indigenous vegetables and pulses (Southampton University); removal of heavy metals and organics from waste water by sulphate reduction (University of London); environmental life cycle assessment of mining and minerals processing (Surrey University); and the use of HPV L1 proteins as potential vaccines (St Thomas's Hospital, London).

Co-operation between Britain and India on R&D projects focuses on the areas of agro-food, telecommunications and manufacturing technologies.



A GEC-Alsthom technician is shown here preparing equipment inside JET – the Joint European Torus – at Culham, in southern England, for experimental work on nuclear fusion as a source of energy. Scientists at JET, the largest fusion project in the European Atomic Energy Community (EURATOM), are currently conducting experiments which, it is hoped, will culminate in the generation of some ten megawatts of fusion power for several seconds – which would represent a major achievement.

A trust has been set up to provide a two-way technology fellowship exchange programme between the two nations.

The Research Councils continue to build close and mutually beneficial links with the major scientific nations through liaison with key organisations and, where appropriate, through the drawing up of agreements which strengthen support for scientist-to-scientist links and facilitate policy discussions. For example, the Biotechnology and Biological Sciences Research Council (BBSRC) has agreements with its counterpart organisations in France, the Netherlands, Japan and South Korea. The BBSRC and the Korean Science and Engineering Foundation are sponsoring a three-year collaborative researcher exchange programme in the area of actinomycete research. Actinomycetes are a group of bacteria that are potentially of great biotechnological use and are being extensively researched in both countries.

Staff in British Embassies and High Commissions conduct government business on, and promote contacts in, science, engineering and technology between Britain and overseas countries. They also help to inform government departments and the scientific community in Britain about scientific developments overseas. There are dedicated science and technology sections in British Missions in Paris, Tokyo, Washington, Peking, Bonn and Moscow. A number of others including Seoul, Rome, Pretoria, Ottawa and São Paulo have officers whose responsibilities include science and technology.

The British Council works in 109 countries, as Britain's principal agency for cultural relations overseas. A significant part of its work is to encourage scientific collaboration by establishing contacts through programmes, exchanges of specialists and policy makers, specialised seminars and other activities. The Council promotes a wider understanding of British scientific excellence and practice through co-operation in research, training and education, priority setting and standards. It supplies information on science and science policy as well as managing technological, scientific and educational projects in developing countries. The British Council funds, with the Research Councils, a joint office in Brussels for providing information to British researchers about European funding opportunities.

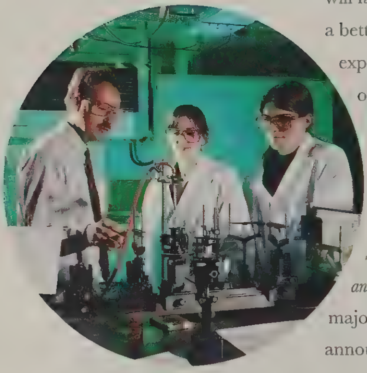
In collaborative work with the University of Chile, scientists at the Institute of Arable Crops Research at Rothamsted, in southern England, have isolated two potent naturally occurring insecticides from a plant, which are effective against important insect pests such as aphids, whiteflies and mites.

Joint work undertaken by the Institute of Grassland and Environmental Research, in Aberystwyth, west Wales, and researchers in several tropical countries has led to novel methods for propagating grass species and forage crops.

Promoting public awareness

Introduction

Although public interest in scientific issues is growing, there is a perceived lack of non-specialist information about scientific and technological activity. By improving the climate for innovation and providing companies with access to technology and best practice, the Government hopes that industry will facilitate the change towards a better understanding and exploitation of the benefits of science, engineering and technology.



School students are shown here learning about lasers at the Rutherford Appleton Laboratory as part of the Pupil–Researcher Initiative, sponsored jointly by the EPSRC and the PPARC.

The 1993 White Paper, *Realising Our Potential: A Strategy for Science, Engineering and Technology*, contained a major policy initiative with the announcement of a campaign to promote the public awareness of science, engineering and technology. This seeks to:

- increase public awareness and appreciation of the contribution that science, engineering and technology make to Britain's economic wealth and quality of life
- raise levels of understanding of scientific terms, concepts and issues, so that public debate on controversial scientific and technological issues becomes better informed.

The Research Councils have an important role in supporting public understanding and awareness programmes.

The Government supports a number of programmes and events, including the National Science, Engineering and Technology Week. The fourth of these Weeks, held in March 1997, consisted of 5,000 events in all parts of Britain. 1997 has been designated the Year of Engineering Success (YES). This initiative is intended to raise public awareness of the role of engineers in wealth creation and life enhancement and is supported by the engineering profession and industry together with government.

The Committee on the Public Understanding of Science (COPUS), set up in 1986, acts as a focus for a wide-ranging programme to improve public awareness of science and technology.

Science festivals

Science festivals are a growing feature of local co-operative efforts to further understanding of the contribution made by science to everyday life. Schools, museums, laboratories, higher education institutions and industry contribute to a wide range of special events.

The oldest and most widely publicised science festival is the British Association Annual Festival of Science when papers are presented on the latest scientific advances. The largest science festival is the annual Edinburgh International Science Festival; in 1996 it included 270 events and attracted approximately 175,000 visitors.

Learned societies

The Royal Society, founded in 1660; is Britain's academy of science and has over 1,100 Fellows and more than 100 Foreign Members. Almost 80 per cent of the money which it distributes is derived from a grant from the Government, the remainder coming from private sources. The Society is involved in a variety of international scientific programmes and facilitates collaborative projects and the exchange of scientists through bilateral agreements with academics and Research Councils throughout the world.

The national academy of engineering in Britain is the Royal Academy of Engineering, founded in 1976. It promotes excellence in engineering for the benefit of society. In 1996 it launched the Engineering Foresight Awards Scheme to enable British engineers to take part in short-term R&D projects overseas on subjects identified in the Foresight Programme.

Scientific museums

The Science Museum in London has an extensive collection of scientific instruments and machinery, complemented by interactive computer games and audio-visual equipment for visitors to use. In this way, the museum explains scientific principles to the general public and documents the history of science. The Natural History Museum, with 68 million specimens, is one of the world's principal centres for research into natural history, offering an advisory service to institutions all over the world.

Other important collections are held by the Museum of Science and Industry in Birmingham, the Museum of Science and Industry in Manchester, the Museum of the History of Science in Oxford and the Royal Scottish Museum in Edinburgh.

Role of women

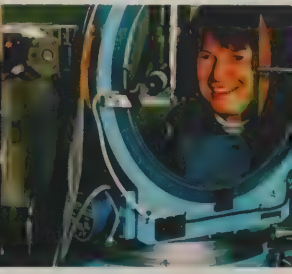
Although the proportion of women working in science, engineering and technology increased threefold between 1981 and 1992, women are still significantly under-represented in these fields, especially in influential policy-making and other senior positions. The Government considers this to be a waste of valuable resources.

Those girls that do study science and other related subjects at school perform as well as boys. The Government seeks to encourage greater numbers of girls and women, including those wishing to combine a career with raising a family, to study science subjects to the highest levels and to pursue life-long scientific careers, by making these careers more attractive and accessible.

A Development Unit on Women in Science, Engineering and Technology was set up in 1994 within the Office of Science and Technology (OST). This has highlighted the economic and other benefits to business of providing a working environment sensitive to the needs of women scientists and engineers wanting to combine a career and family responsibilities. It aims to: raise awareness of the contribution women can make in the science and technology field; ensure relevant careers information is widely available; and promote good employment practices. Measures are being taken by government and others to publicise best practice in areas such as childcare, job sharing, flexible working and career breaks.

Scientists working in a new laboratory at the University of Bristol are studying organic residues found in ancient pottery. In collaboration with the University of Manchester Institute of Science and Technology, the Bristol team, one of whom is shown here, has recently found the first evidence for the existence of DNA in ancient materials.

Below the recently reconstructed Palm House at London's Royal Botanic Gardens, Kew, a new permanent exhibition has been created to display marine plants from around the world.



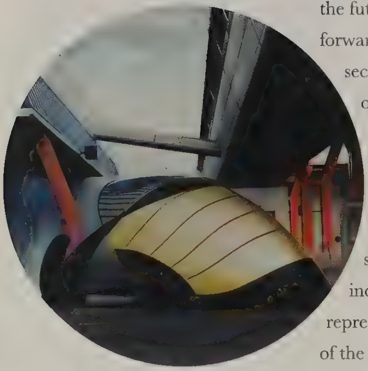
Professor Judith Howard, Head of the Department of Crystallography at the University of Durham, next to the ultra-low temperature diffractometer she has developed. Professor Howard uses this revolutionary tool for her studies on the crystalline structure of organic metals and thin films, essential materials for bio-sensors and a number of other concepts with commercial applications.

Encouraging collaboration between the science base and industry

Foresight Programme

The Foresight Programme was introduced in 1993. Its aims are to bring together business, the science base and government to establish visions of the future – identifying the opportunities, the threats, and the developments in science and technology that will help us meet our future needs – and to act on the priorities identified.

Foresight is about preparing for the future, creating a culture of forward-thinking across all sectors of the UK economy in order to secure sustained competitive advantage and enhanced quality of life.



Commissioned by the Society of Motor Manufacturers and Traders to celebrate 100 years of the British motor industry, Concept 2096 symbolises the kind of driverless, wheelless, computer-controlled car that could be on the road at the end of the next century. The full-size clay model was designed and built jointly by a team at Coventry University and a Coventry-based company, Geoff Mathews Design.

The Programme is spearheaded by 16 independent panels, each representing an important sector of the UK economy. The panels comprise representatives from business, the science base and government. Following widespread consultation involving some 10,000 people, the panels published their first reports and recommendations in 1995. The panels continue to build on their findings.

The outcome of Foresight is being used to influence public sector science and technology policy and spending decisions. Well over £350 million has now been committed to initiatives reflecting Foresight priorities. These include: the Foresight Challenge competition, which is providing £92 million for projects bringing together business and the science base to address Foresight priorities; £10 million of government funding for the new Foresight LINK Awards, announced in July 1997; and 17 new LINK programmes reflecting Foresight priorities, worth over £140 million in total. Other government departments and Research Councils continue to re-align existing programmes to Foresight priorities, introducing new initiatives where appropriate.

The new Government has put Foresight at the heart of its policy on business competitiveness. It has introduced new initiatives which build on Foresight recommendations for improved quality of life and sustainable development, and has undertaken a detailed audit of Foresight in government departments in order to improve co-ordination of the Programme across Whitehall.

The £10 million Foresight Vehicle LINK programme, launched in June 1997, will bring together UK resources and expertise to develop the technologies and components for the car of the future – leading to vehicles that are cleaner, safer and easier to drive.

Researchers from business and the science base will be working together on such things as exploring environment-friendly alternatives to present-day engines; developing advanced electronics and systems to monitor car and traffic conditions; and making vehicles out of more fuel-efficient, durable and recyclable materials.

Realising Our Potential Award (ROPA)

ROPAs reward researchers who have won funds from industry for basic or strategic research with the chance of funding to carry out new, speculative research projects of their own choosing, entirely separate from the work funded by industry. 233 new ROPAs worth £19.5 million were announced in June 1997. In assessing ROPA proposals, the touchstone is originality. Blue-skies, curiosity driven research has been the basis of Britain's great scientific discoveries. The Government is committed to giving such research the strongest possible support.

New ROPAs awarded in 1997 support, for example, investigation of new neurological means of

Clinical interest in sports injuries and their repair is stimulating a number of research programmes in Britain. At the forefront of this work is the Interdisciplinary Research Centre (IRC) in Biomedical Materials, based at Queen Mary and Westfield College, part of the University of London. As part of a Department of Trade and Industry (DTI) and Engineering and Physical Sciences Research (EPSRC)-funded LINK programme, IRC researchers use a variety of machines designed and built in association with the Smith and Nephew Company to test models of human joints, such as the knee joint shown here.

In a ROPA-funded MRC project at St Mary's Hospital Medical School, London, Dr Simon Trom is using changes that occur in the blood vessels of the retina as possible indicators of heart disease and stroke.

reducing chronic pain in arthritis sufferers, research on the chemistry of fuel cells with both technological and environmental implications, investigation of water permeability and the preservation of rare wetlands, and research on the implications of infant nutrition for adult health.

Co-operative Awards in Science and Engineering (CASE)

The Government makes funds available through the Research Councils for the CASE scheme, which supports students on research projects jointly supervised with industry.

LINK

The LINK scheme provides a government-wide framework for collaborative research in support of wealth creation and improvement of the quality of life. It aims to promote partnerships in high-quality, commercially relevant research projects between industry and higher education institutions and research bodies. Government departments and Research Councils fund up to 50 per cent of the cost of projects, with industry providing the balance.

LINK is now operating through 56 programmes. Over 800 projects worth approximately £410 million have been started, involving over 1,100 companies (of which some 350 are small or medium-sized enterprises) and 180 research base institutions.

Since a relaunch of LINK in 1995, 17 new programmes have been announced in response to priorities identified by the Foresight Programme.

Celsis International, a leading medium-sized biotechnology firm, is creating 'Celsis Connect' with support from the Biotechnology and Biological Sciences Research Council (BBSRC), DTI and industry. It comprises six R&D projects being undertaken under the LINK scheme at Celsis in Cambridge, together with three university-based projects, all designed to improve industrial microbial monitoring throughout manufacturing industry. The programme also receives technical and financial support from over 40 international companies and organisations active in eight different industrial sectors.

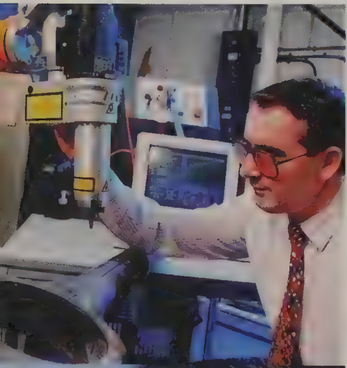
The overall objective is to replace traditional methods of testing with easy-to-use, rapid-testing systems capable of generating accurate and reliable data in hours and minutes, rather than days. The projects focus on crucial unresolved problems such as rapid sterility testing, high sensitivity hygiene monitoring and rapid pathogen/specific organism identification. They employ the latest technologies, including advanced bioluminescence, enzyme amplification, molecular biology and microbial physiology.

Teaching Company Scheme (TCS) and Postgraduate Training Partnerships (PTP)

The DTI supports the transfer of technology, knowledge and skills between the science base and business through a variety of schemes and arrangements. Among these are the TCS and PTP, neither of which are exclusively DTI initiatives. Both depend on academics and company personnel jointly supervising high-quality graduates working on industrially-related research or technology transfer projects.

Each TCS programme involves one or more high quality graduates (TCS associates) working in a company for two years on a project central to the company's needs. At present, there are about 625 TCS programmes with over 1,000 graduate places. With part-funding from a government grant to the university 'partner', the company contributes a variable amount to the direct costs of the programme. Around 75 per cent of current TCS programmes are with small and medium-sized enterprises.

Under the PTP initiative, up to ten postgraduate students (PTP associates), are recruited annually into each of eight 'Partnerships'. PTP associates are registered for a higher degree (normally, a three-year PhD) and undertake industrially-relevant research projects at a Research and Technology Organisation (see p. 20) under the joint supervision of academics and industrialists. The aim is to increase the number of high-quality postgraduates with skills, experience and training relevant to the needs of industry.



Although robots are now commonplace in industry, particularly for spray painting and welding, most will try to carry out their program even if something gets in their way. Now, thanks to a SMART award, Meta Technology of Didcot, in southern England, has used the power of neural computing – linking computers in the way nerves are connected in the brain – to develop a system that enables machines such as this welder to adapt to changes in the area in which they operate.

A non-contact probe that measures the properties of human skin has earned its British developer, DiaStron Limited of Andover, southern England, a SMART award. The DiaStron system has applications in the personal products industry, testing the claims made for skin and haircare creams and lotions, as required by recent European legislation.

Small Firms Merit Award for Research and Technology (SMART) and Support for Products Under Research (SPUR)

In April 1997, DTI announced a new scheme in England combining SMART, SPUR and the innovation element of Regional Enterprise Grants. Assistance is now available through a single SMART scheme for technical and commercial feasibility studies into innovative technology and for development up to pre-production prototype stage of new products and processes involving a significant technological advance.

Awards are made on a competitive basis. Individuals and independent small businesses with fewer than 50 employees may submit proposals for support with feasibility studies. Assistance is 75 per cent of eligible project costs up to a maximum grant of £45,000. Independent businesses with fewer than 250 employees may compete for support with development projects. The award in this case is 30 per cent of eligible project costs up to a maximum grant of some £147,000.

The Scottish Office Education and Industry Department and the Welsh Office Industry and Training Department operate their own schemes. SMART provides support for feasibility studies and SPUR provides support for development of new products and processes, with eligibility criteria and levels of awards similar to those in England under the unified scheme. The Industrial Research and Technology Unit in Northern Ireland's Department of Economic Development also runs a SMART scheme for feasibility studies. SMART winners in Scotland, Wales and Northern Ireland may apply for SPUR awards to continue development of their projects.

Over 2,500 projects have been supported under the SMART and SPUR schemes.

Science parks

Science parks are partnerships between higher education or research centres and industry to promote commercially focused research and advanced technology. There are around 50, which are host to more than 1,200 companies. Most of these are engaged in computing, biotechnology, chemicals, electrical engineering and robotics. Technology transfer and R&D are the most common activities, rather than large-scale manufacturing.

A growing number of universities offer industry inter-disciplinary research centres. These include access to analytical equipment, library facilities and worldwide databases as well as academic expertise.

Industrial Research and Technology Organisations (RTOs)

RTOs are independent organisations which together employ over 10,000 people. Britain has the largest RTO sector in Europe, consisting of around 70 organisations. RTOs conduct confidential strategic research which companies need for their next generation of products or services. They may develop new products and carry out routine testing, particularly relevant to small companies which may not be able to afford the necessary advanced instruments.

Technology transfer

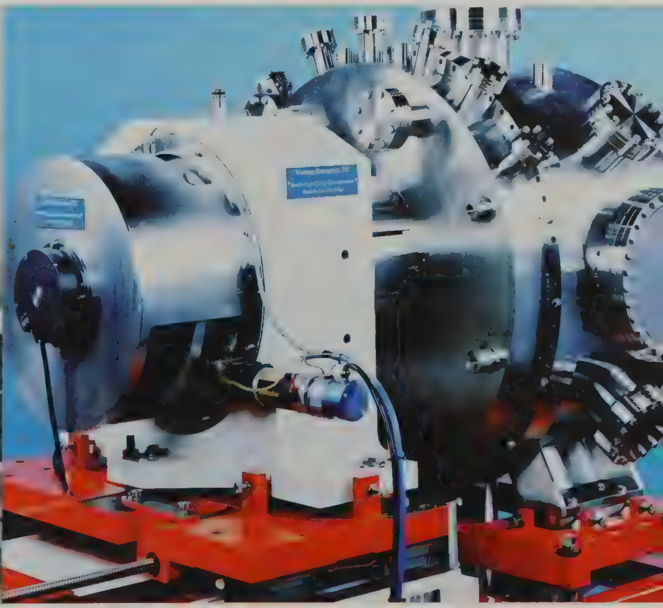
The overwhelming majority of technology transfer takes place 'naturally' through normal business activities without the help of government. However, the Government recognises that there are key areas where it can help address 'market failures' productively and improve competitiveness. The DTI spends over £50 million a year on a range of technology transfer and best practice activities to increase the number and quality of partnerships between the science, engineering and technology base and industry, to improve access (particularly for small and medium-sized businesses) to sources of technology and technological expertise, to improve the capacity of firms to use technology effectively and to increase the demand for modern technology and best practice techniques.

Various mechanisms are used, including:

- programmes designed to strengthen the partnership between industry and the science base and foster a favourable innovation climate, such as the Foresight Programme and the work of the DTI's Innovation Unit
- technology and knowledge transfer through people placement schemes, such as TCS, whereby links are forged between academia and industry
- international technology services, which help firms gain access to overseas technology and best practice through technical missions, secondments, information dissemination and International Technology Promoters
- management best practice schemes to help firms improve business management skills, promote 'benchmarking' and learning from 'exemplar' companies, thereby equipping firms to make better use of technologies
- specialist Innovation and Technology Counsellors and Design Counsellors in Business Links to provide firms with advice and access to the best sources of technical help and best practice
- Focus Technical, a programme which encourages RTOs to focus on the needs of smaller companies.

There is a wide range of intermediary organisations which assist firms on a sectoral, regional and discipline basis. Together with support from industrial liaison groups in universities, from patenting and licensing organisations and from providers of 'seed' and venture capital, Britain is thus able to offer companies comprehensive assistance in all aspects of technology transfer.

To advance gas-turbine technology in both aerospace and industrial power generation applications, Rolls-Royce has set up a series of University Technology Centres (UTCs) around Britain. The main aim of the UTC at Cambridge University is to help develop the next generation of high-temperature materials, one of which is shown here being tested.



In a recent collaboration between the Daresbury Laboratory in Cheshire, north-west England, and the instrument company VG-Fisons, a licence has been obtained to export five newly-developed X-ray monochromators, one of which is shown here, to the Advanced Photon Source at the Argonne Laboratory in the United States.

Physical sciences

Computer-generated picture of the design for the Gemini 8-metre telescope being constructed on Mauna Kea, Hawaii.

Astronomy

Astronomy and astrophysics concentrate on understanding how stars and galaxies formed and have evolved, and on working back to the characteristics of the 'big bang', as well as testing the laws of physics under conditions totally inaccessible to laboratory experiments. Britain remains at the forefront of this research, a major reason being the continuing development of instruments.

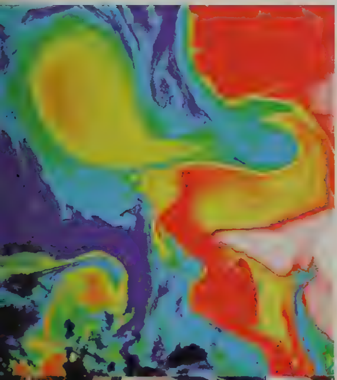
In observational astronomy exciting discoveries have been made with the Particle Physics and Astronomy Research Council (PPARC)'s network of telescopes at home and abroad, both ground-based and in space. The PPARC is a principal partner in the international La Palma Observatory in the Canary Islands. The observatory's four telescopes include the 4.2-metre William Herschel, the third largest single-mirror optical telescope in the world. On Mauna Kea, Hawaii, it has a 3.8-metre infra-red telescope, the largest such telescope in the world, and the 15-metre James Clerk Maxwell millimetre wavelength radio telescope (built in collaboration with the Netherlands and Canada). In 1992, using the Mauna Kea infra-red telescope, a team of British and US astronomers discovered a rare form of hydrogen associated with auroras, H_3^+, around the polar regions of Saturn.

Through the PPARC, Britain is taking part in one of the most important ground-based astronomical projects – Gemini, an international collaboration to build two 8-metre telescopes that will give all-sky coverage from sites in Hawaii and Chile. These are due to be completed in 1999 and 2001 respectively. The other partners are Argentina, Brazil, Canada, Chile and the United States. Britain has major responsibility for the primary mirror support system and much of the control software.

Radio astronomy telescopes based in Britain complement the work of British optical, infra-red

Intricate sea temperature patterns are described in this image taken by the ERS-1 satellite orbiting above Japan's Honshu Island. In addition to their usefulness in studying ocean dynamics, images such as this are exploited by fisheries, since fish are known to gather at the fronts between warm (yellow) and cold (blue) water.

British space engineers working for Matra Marconi Space, which is based in Bristol, in the west of England, have built a full-scale replica of the European Polar Platform, intended for launch in 1999. Their model will now be extensively tested at the European Space Technology Centre in the Netherlands to observe its reaction to space conditions.



and millimetre wave telescopes on overseas sites as well as the British and European Space Agency (ESA) space programmes. Manchester University Radio Astronomy Laboratories at Jodrell Bank is one of the world's leading centres for radio astronomy.

For projects which need high resolving power (the ability to see fine detail), Jodrell Bank scientists have adopted a method - invented at Cambridge University in the 1950s of making small radio telescopes imitate much larger telescopes by linking them electronically. The MERLIN (Multi-Element Radio Linked Interferometer Network) is Jodrell Bank's array of seven observing stations that together form a powerful telescope with an effective aperture of over 230 kilometres.

Black holes

Black holes are collapsed stars where gravity is so strong that light cannot escape. In 1993, using new infra-red technology, astronomers at Keele and Oxford Universities 'weighed' the compact stellar object in an X-ray binary (double-star) system and found it to be a black hole of 16 solar masses. British astronomers developed a new method of determining the mass of compact stars in these binary systems.

Space activities

Britain's support for civil space is co-ordinated by the British National Space Centre (BNSC), a partnership of government departments and Research Councils. Through BNSC, Britain spends around £200 million annually on space activities, some two-thirds of which is devoted to collaboration with other European nations in European Space Agency programmes.

Around half of Britain's space programme is concerned with satellite-based Earth observation (remote sensing) for commercial and environmental applications, using satellite-borne instruments. Satellite data has considerable commercial potential: applications include mapping, crop monitoring, oil and mineral exploration, fish location, weather forecasting and sea ice monitoring.

Britain has made major investments in ESA's European Remote Sensing satellites ERS-1 and ERS-2, launched in 1991 and 1995 respectively. The British contribution to the ERS satellites included a synthetic aperture radar (SAR) and an along-track scanning radiometer (ATSR). The SAR is capable of supplying high resolution images of the earth 24 hours a day, irrespective of cloud cover. The ATSR measures global (sea and land) surface temperatures. British-built remote sensing instruments are also being flown on other satellites, including the Upper Atmosphere Research Satellite.

The National Remote Sensing Centre at Farnborough (Hampshire) houses one of ESA's four processing and archiving facilities which store and distribute remotely-sensed data for both scientific and commercial purposes.

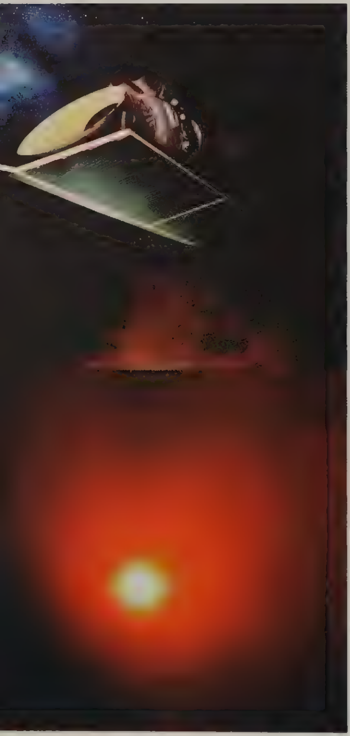
Britain's main current investment is in the ESA ENVISAT-1 Earth observation mission due to be launched in 1999. The ENVISAT payload comprises a new generation of ESA environmental instruments. Britain is leading the development of ENVISAT's advanced radar and an advanced ATSR instrument to measure infra-red emissions over land and sea. The satellite is being assembled at the Bristol facility of Matra Marconi Space UK.

In space science, Britain participates in ESA's Science Programme through PPARC (one of the BNSC partners). A quarter of Britain's space budget goes to science, including astronomy, planetary science and geophysics. Missions range from the Hubble space telescope to the Ulysses solar probe. The Hubble space telescope, launched in 1990, carries British-built solar arrays and the Faint Object Camera, which have helped advance knowledge of the nature and origins of the Universe. Britain is contributing substantially to the SOHO mission to study the sun. It is also participating in XMM, the ESA's X-ray spectroscopy mission, due for launch in 1999.

ESA's Infrared Space Observatory (ISO), which was launched in 1995, carries a number of scientific instruments developed in Britain. It is being used to study a wide range of phenomena, including the centre of the Milky Way which may house a black hole.

There are bilateral agreements for space research between Britain and other countries, such as the United States (through NASA), Russia, India and Japan. British scientists have developed, for example, the widefield camera for ROSAT (the German, British and US X-ray satellite), a spectrometer for the Japanese-built Yohkoh satellite and an X-ray telescope for the forthcoming Russian Spectrum-X mission.

Britain is both a leading producer and user of satellite communications technology.



Launched in November 1995 by the Ariane 4 launcher, the Infrared Space Observatory (ISO), shown here as an artist's impression, has provided astronomers with an unprecedented facility for detailed exploration of the Universe.

One of a series of infrared images obtained by ISO's camera of the comet Hale-Bopp in October 1996. The chief feature is the cloud of dust in the comet's head (coma). The bright region is about 100,000 kilometres across, or more than seven times wider than the earth.

Nuclear and particle physics

Research in nuclear structure physics and particle physics is supported by the Engineering and Physical Sciences Research Council (EPSRC) and the PPARC respectively, and co-ordinated by the Council for the Central Laboratory of the Research Councils (CCLRC). In recent years British physicists have made significant advances in nuclear structure research, including: the original discovery of super-deformed, rapidly spinning nuclei; the discovery of new examples of proton radioactivity; and important studies of the clustering of nuclei – the so-called nuclear module.

British and French scientists have constructed Eurogam, the world's most advanced gamma ray spectrometer. Eurogam's detector array is used to study nuclear matter under the most extreme conditions, such as nuclei rotating at extreme velocities. It operates in conjunction with the Daresbury Recoil Mass Separator, a highly sensitive device for identifying species of nuclei which emit gamma rays. Together they provide an unparalleled facility for studying the nucleus.

Scientists at the University of Surrey are studying nuclei in highly excited 'spin trap' states in which they cannot lose energy and some of the neutron or proton pairs are broken, gaining a better understanding of nuclear structure and leading to the possibility of gamma-ray lasers.

An atomic nucleus behaves similarly to a spinning egg. An excited nucleus loses energy by emitting gamma-rays as its spin slows down. It has been established that nuclei spin like 'superfluid' eggs, with superfluidity resulting from neutrons or protons orbiting in pairs – just as paired-electron orbits give rise to superconductivity. If a superconductor is heated, the electron pairs are disrupted and the superconductivity is destroyed, but how the uncoupling of nuclear pairs erodes the superfluidity remains a puzzle.

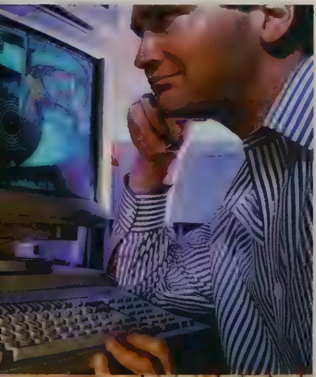
In order to study spinning nuclei, beams of heavy ions are used, which hit targets with enough energy to create nuclei in spin-trap states. Their decay gamma-rays can then be detected after the beam has been turned off – when more than 99 per cent of the reaction gamma-rays have already been emitted.

Working with pulsed heavy-ion beams at the Australian National University, the Surrey group has revealed for the first time a rotating eight-particle spin trap in the isotope tungsten-178. The new trap spins much like the nuclear equivalent of a hard boiled egg, indicating that the superfluidity has almost gone. These results are leading to new ideas for exploring the limits to the existence of these exotic states of matter. There is also the possibility of using radioactive nuclear beams.

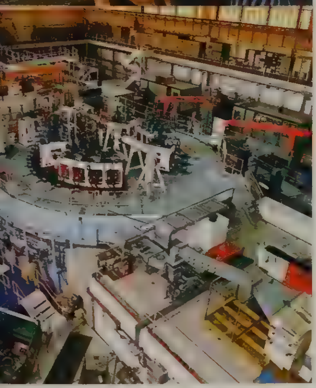
Particle physics experiments often require the use of large colliders and accelerators. They form the basis of a number of international collaborations, performed at overseas laboratories, particularly the European Laboratory for Particle Physics (CERN) in Geneva, which is supported by 19 member states including Britain. Scientific programmes at the CERN aim to test, verify and develop the 'standard model' of the origins and structure of the universe.

The current CERN programme is focused on the Large Electron Positron Collider (LEP), the world's biggest operating particle collider, with British physicists and engineers collaborating in the design and construction of three of the four highly sophisticated experiments currently in progress. The CERN has recently installed 84 new superconducting accelerating cavities on the Large Electron Positron Collider, known as LEP2.

British physicists are playing an important role in designing experiments for the new Large



Automated recognition of people by examining the pattern of the iris of the eye offers major advantages over conventional identification techniques, such as fingerprinting. Here, Dr John Daugman is studying an iris image using a system he has developed at Cambridge University. One of the first applications of Dr Daugman's technology is to identify users of automated teller machines, or cash dispensers, through the use of a built-in 'smart' camera.



The ISIS facility at the Rutherford Appleton Laboratory in Oxfordshire is the world's most powerful source of pulsed neutrons and muons. International teams of researchers are employing its beams to investigate the fundamental structure of matter.

Hadron Collider (LHC) to be built at CERN, which will be ready in 2004. The LHC will allow physicists to smash particles together at higher energies than ever before, giving them the chance to look for particles which require far more energy to create than is available at LEP, in the process advancing their study of the particles that make up the universe and the forces that act on them. The collisions will recreate the conditions prevailing in the universe just 10 to 12 seconds after the 'big bang'.

Scientists from Britain are also collaborating in the two major experiments to explore the internal structure of the proton and its constituents at the Hadron Electron Ring Accelerator (HERA), the electron–proton collider at the Deutsches Electronen Synchrotron (DESY) Laboratory in Germany.

The BaBar experiment in the major new detector to be built at the Stanford Linear Accelerator Centre in California will address one of the key physics issues – the understanding of the asymmetry between matter and antimatter. Ten British institutions will take part in BaBar, in conjunction with nine other countries, involving an international team of nearly 500. British firms will construct advanced technology equipment for BaBar, which is due to begin full operation in 1999.

A project between scientists at the University of Huddersfield and chemicals manufacturer Allied Colloids has led to the development of a pilot bioreactor for manufacturing high quality ammonium acrylate, an important component of industrial polymers. Strains of bacteria were identified that contained the enzymes necessary for the conversion of acrylonitrile into ammonium acrylate. In the experimental bioreactor ammonium acrylate was produced with the same polymerisation characteristics, functionality and purity as that made by conventional chemical synthesis.

Engineering and materials

ISIS and the Synchrotron Radiation Source (SRS) are facilities for studying the physical and chemical structure and behaviour of materials and substances. They support the physics, chemistry, biology, materials and engineering communities across a broad range of applications.

The ISIS machine, housed at the Rutherford Appleton Laboratory in Oxfordshire, is used by research teams from over 30 countries to probe with pulsed neutrons and muons the structure and dynamics of solids and liquids, including high-temperature superconductors, on an atomic scale. It is also used to determine three-dimensional residual strains and stresses in engineering components.

The Synchrotron Radiation Source at the Daresbury Laboratory in Cheshire provides very high-energy radiation, from X-rays to the infra-red part of the electromagnetic spectrum. It is used by some 2,000 British and overseas scientists to investigate: the expression and suppression of genes and the reactions when chemical 'messengers', large protein molecules, arrive at receptor sites in living cells; and the effects at the boundaries between two different materials in semiconductors.

The Centre for Process Systems Engineering, an interdisciplinary research centre (IRC) based at the University of London, studies the design, control and management of process plants. These complex systems transform raw materials in a combination of chemical, physical and biochemical processes. There can be thousands of variables that operators can modify to improve performance of the plant. The IRC conducts experiments on process plants by 'building' them inside computers, employing sophisticated algorithms based on complex mathematical concepts. It combines theoretical work on systems with experimental studies on working plant.

The Biocomposites Centre at the University of Wales is exploiting renewable resources as industrial feedstocks, showing how plants can be used to make advanced materials, such as composites. The role of chemically-modified plant fibres in environmental clean-ups, novel approaches to chemical pumping and the use of ultrasonics to speed up large-scale chemical reactions are among the areas being explored.

Electronics and communications

British researchers have been responsible for important inventions in radio, television and radar, which formed the basis for the development of the modern electronics industry. Current research areas cover optoelectronics, molecular electronics, advanced control technology, advanced silicon technology and design automation. Priority areas include software and supercomputing in engineering.

Electronic systems in computer-aided design, process control instrumentation and robotics are commonplace in manufacturing industry. Companies such as GEC and Oxford Instruments develop analytical instruments for industrial research and advanced electronic medical equipment. British firms, like Racal and Cossor, are still in the forefront of technological advances in radar.

Superconductors

New ceramic materials developed by GEC-Marconi may prove to be superior to existing high-temperature superconductors (materials with low electrical resistance). Materials based on cadmium, lead and copper oxides have been found to be both stable and reproducible. By the end of the 1990s further developments are expected to lead to applications in power generation and transmission, electromagnetic stores for electricity and transport systems using magnetic levitation. The world's highest-temperature superconductor is being produced at Cambridge University.

Information technology and computing

Britain has made important contributions in opto-electronics (the combination of optics and electronics) and parallel computing, which is based on transputers working in parallel to give the same capacity as a supercomputer. In 1983 Inmos produced the transputer, which combines all the main functions of a simple computer on a single chip.

Firms and research organisations have been engaged in the development and application of the new family of 'three–five' semiconductor materials (such as gallium arsenide). In 1984 GEC released the first commercially available gallium arsenide microprocessor, which can operate at much higher frequencies than the common silicon type. The Trax, a novel design of supercomputer processor with multiple applications, including high-definition television and defence

A centre dedicated to the study of microporous materials has recently been established by a consortium of leading British industrial companies. One of the current projects at the Centre of Excellence for Research on Microporous Materials, based at the University of Manchester Institute of Science and Technology, in northern England, is to find ways to distil plastic waste into fuel. Dr Vladimir Zholobenko is shown here using the Centre's infra-red spectrometer to examine crystals of a material that catalyses the distillation process.

A virtual reality model of a major Imperial Chemical Industries (ICI) petrochemical plant has been developed by VR Solutions Limited of Salford, northern England, for training, construction planning and health and safety studies.

systems, was originally developed at Brunel University.

Silica glass is widely used as an optical fibre material, with millions of kilometres of fibre circling the globe. For many applications the inert and stable nature of silica, which makes it ideal for passive communications, renders it a poor host for active use. Hence, new optical amplifiers and lasers require new types of glass to meet their requirements. At the Optoelectronics Research Centre at Southampton University, efforts have been directed to a novel material group – the chalcogenides – for active fibre devices. New laser transitions can be achieved in this glass, providing amplification at 1.3 microns, the wavelength at which the majority of the world's land-based optical fibre operates.

British companies are in the forefront of software development. Major advances are being made in the field of 'virtual reality', a three-dimensional computer simulation technique with industrial and other applications. A Salford-based company, VR Solutions, is conducting research into virtual reality technology. Virtual reality is being used to design buildings and a whole range of products, including cars, pharmaceuticals and machine tools.

The Mobile Multimedia project will develop several prototype distributed multimedia applications which can operate over mobile networks and are specifically tailored for use by the emergency services. The work is being undertaken by Professor Hutchison of Lancaster University. Custom-designed protocols will facilitate effective communication between different media types, including audio and video.

Supercomputing

The Cray T3D service at Edinburgh Parallel Computing Centre (EPCC) is a national facility for use by researchers supported by the Research Councils. The Cray T3D has 512 processors and an overall memory of 32 GBytes. Researchers work in consortia (usually including international collaborators), sharing expertise in their area of computational research. The CCLRC also runs scalar and vector services on behalf of the other Research Councils from its Rutherford Appleton and Daresbury Laboratories.

British Telecom (BT) and the academic community are collaborating on the development of SuperJANET (the Super Joint Academic Network), a new high-speed fibre optic network linking computer systems in academic and research institutions in Britain. SuperJANET will complement the Joint Academic Network (JANET) currently linking 200 sites. It can transmit the equivalent of a 5,500-page report in less than one second.

The Interdisciplinary Research Centre in Biomedical Materials at the University of London is a national focus for research into biomaterials for implants, with particular emphasis on orthopaedic, dental and

At Rolls-Royce's Gas Turbine Materials Centre in Derby, central England, intensive research and development programmes are under way to increase the proportions of composite materials used in aero engines. Pictured here is a Rolls-Royce technician using a test rig to investigate the strength of a ceramic component at high temperature.

Drinking water of a quality even higher than the strictest European Union/British standard is the goal behind new and advanced treatments that are being tested and developed at a specially built research centre in southern England. Thames Water's Advanced Water Treatment Centre, in west London, shown here, was built to test new filtration materials and processes.

cardiovascular applications. It researches many aspects of the skeleton and materials which come into contact with the body – contact lenses and equipment used in surgery, for example. It also studies biodegradable polymers and composites. These materials can play a role in drug delivery and in fixing fractured bones.

The Centre's artificial bone known as HAPEX is a composite of a polyethylene and hydroxypapatite, a ceramic similar to the structural component of the human skeleton. It is estimated that an artificial hip made from this material will last for about 25 years, while existing metal artificial hips last around 15.

Telecommunications

BT has led in the development of optical fibre communications systems. It is currently working on advanced optical and radio network technology for lower-cost communications, and on software engineering to provide better managed and more 'intelligent' national and global networks. Additionally, it is employing speech, data and visual technologies in the production of the videophone, video-conferencing and teleworking. Around two-thirds of BT's research is in software engineering. GPT, Britain's largest telecommunications manufacturer, has made substantial progress in voice processing, computer-assisted telephony, videotelephony and videoconferencing.

Drugs, building materials, electronic components, vehicle parts, waste treatment and water purification products are all reliant on materials made from catalysis. New and improved catalytic processes, which could dramatically change the economic and environmental performance of the British chemicals industry, are to be developed by a research consortium made up of 20 British companies, including ICI, and 44 academic departments.

As technology leads to smaller, less obtrusive and less power-hungry equipment, BT's 'office on the arm', originally announced in 1994 as a futuristic idea, is now a fully working prototype. Developed at its laboratory in Martlesham, eastern England, the equipment can be strapped to the arm and used with a virtual reality headset and microphone.

Engineering student numbers in the Aeronautical Department at London's City University have increased by 70 per cent since the installation of this low-cost flight simulator, designed and built by Merlin Products of Sussex, southern England. The students programme their design modifications into the simulator's computer to test their effects on handling.

The West Midlands-based telecommunications company GPT has recently been given China's official sanction to construct one of the longest synchronous digital hierarchy (SDT) transmission routes in the world. SDT technology allows faster and more efficient transmission of data across a network than earlier systems. Pictured here is a GPT technician inspecting a printed circuit board prior to X-ray verification.

Aerospace

Britain has led the world in many aspects of aerospace R&D over the last 80 years. Pioneering achievements include vertical take-off and landing, flight simulators, swing-wing military aircraft, 'fly-by-wire', 'head-up' displays and ejector seats. About 10 per cent of Britain's investment in industrial R&D goes to the aerospace industries. Most developmental work is carried out by industry, with some assistance from government research establishments. Long-term research work is undertaken in partnership with universities and industrial research centres.

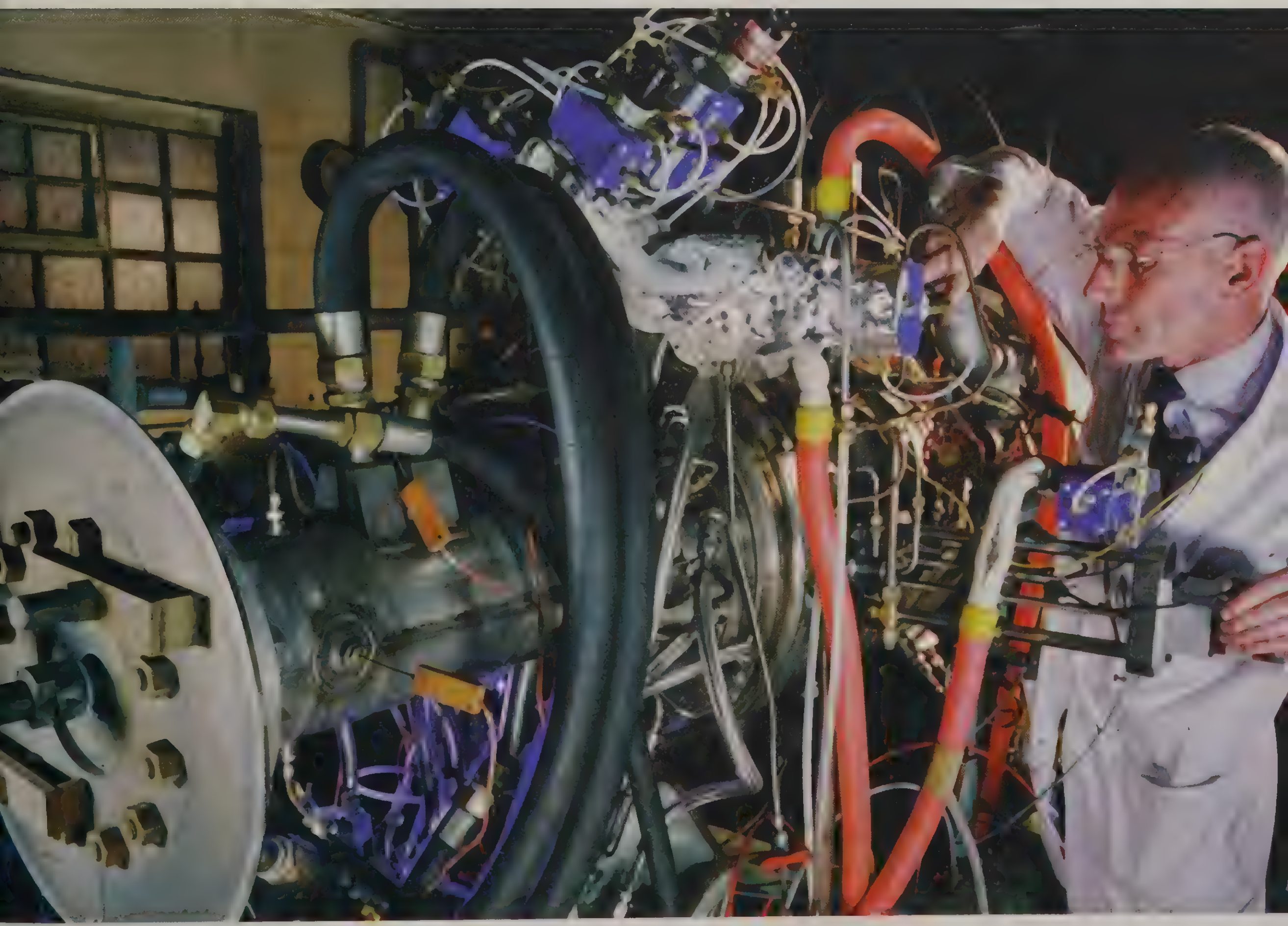
Aerospace engines

Research and development in aerospace engine technology is dominated by Britain by Rolls-Royce. Its most important civil engine is the RB211 turbofan, featuring wide-chord fan blades, together with an electronic fuel control system, giving improved thrust and fuel efficiency.

A market leader is the latest Rolls-Royce engine, the Trent 900, an 80,000 lb-thrust engine derived from the Trent 800 which powers the Boeing 777 twin-jet airliner.

Launched in September 1996, the Trent 900 is being developed to power future ultra-high-capacity airliners. It will offer substantial weight and performance advantages over the competition, and noise levels will be no higher than for the current Boeing 747-400.

Cranfield University recently celebrated its 50th anniversary as Britain's foremost aeronautical teaching and research establishment. Shown here is one of the university's recent developments: a real-time flight simulator that provides an environment for testing prototype aircraft displays, flight control systems and avionics.



Life and medical sciences

A new way of separating and purifying protein pharmaceuticals has been developed by Cambridge University and Affinity Technology Limited. The new method, shown here, allows scientists to separate a particular protein from other molecules using custom-designed compounds that, following immobilisation of solid support particles, bind the protein of interest and allow impurities to pass down the column unhindered.

Introduction

Far-reaching scientific advances are being made in Britain in genetics, medicine, biotechnology and pharmaceuticals. Britain has a particularly strong reputation in protein engineering and antibody research, and many British research teams working in the life sciences have established international reputations.

EQUAL – Extending Quality of Life

EQUAL spans research in medicine, genetics, cell biology, diet and nutrition, neuroscience, chemistry, engineering, and materials, as well as socio-economic research into the role of the elderly in society. Five projects were announced in June 1996 – in the health and life sciences sector – including research by multi-disciplinary teams into ways of detecting and preventing Alzheimer's disease, investigating the causes and consequences of strokes and improving the discovery and design of drugs aimed at older people.

The aim is to develop ways of detecting the disease using brain imaging technologies. The New Centre for Research into Strokes involves SmithKline Beecham, Beecham Pharmaceutical and the University of Cambridge. Disease in blood vessels supplying the brain can result in strokes. This project aims to gain an understanding of the cause and consequences of the disease, to develop new treatments and to improve existing ones. With the need to develop new drugs to cope with illnesses in an older population, pharmaceuticals firms are seeking to improve the rate of drug discovery by screening thousands of compounds at the same time, using new technology.

Protein engineering

A Centre for Protein Technology has been opened at the University of Edinburgh. Proteins are a very varied family of chemicals with fundamental roles in all aspects of living systems. They include enzymes, the most powerful and specific catalysts known, capable of speeding up the most sluggish chemical processes by a million-fold. Researchers hope to exploit this capacity to produce chemicals such as antibiotics, flavourings and fragrances. Proteins are also fundamental to health and disease. Scientists will explore ways of inactivating rogue proteins in disease states, and the possible use of proteins as drugs with applications ranging from Alzheimer's disease to rheumatoid arthritis. The unique three-dimensional structure and biological function of selected proteins and glycoproteins will be studied using a combination of recombinant and chemical synthesis, high field nuclear magnetic resonance and X-ray crystallography.

Genetics

Britain is in the forefront of genetics research, and is one of the main countries engaged in the process of isolating and mapping the complete sequence of genes – the genome – in the cells of humans. The research, and the study of gene products, has vast potential for the understanding of human biology and many diseases.

A major national research project financed by the Medical Research Council (MRC) is the Human Genome Mapping programme, involving mapping of the complete sequence of 100,000 genes in a human cell. The European Bioinformatics Institute (see p. 13) is playing a major role in making the growing body of information from genome research and molecular biology accessible to the European scientific community.

Several thousand of these genes have already been identified. In the process of locating the position of all the DNA and decoding the genetic information it contains, genetic defects linked to a number of diseases have already been localised. These include cystic fibrosis, for which a gene therapy is already being tested, Alzheimer's disease, retinoblastoma (eye cancer) and muscular dystrophy.

Advances in the rapidly developing field of human genetics offer great potential for improving the quality of life. However, such developments also raise concerns. The Human Genetics Advisory Commission (HGAC), a non-statutory advisory body of independent members, was established in 1996 by the Government to consider the broad social, ethical and economic consequences of developments in human genetics (for example in relation to public health, insurance, patents and employment). The HGAC will also advise the Government on ways to build public confidence in the new science. The HGAC is chaired by Sir Colin Campbell and reports to both industry and health Ministers. The secretariat is based in the Office of Science and Technology.

A further initiative in the genetic approach to human health will build on the Human Genome Mapping Project, encompassing all aspects of genetic diseases and their future treatment. It will include establishing centres of expertise in gene therapy, whose aim will be to treat patients with inherited disease by inserting a healthy copy of a faulty or missing gene into cells in the patient's body.

Fluorescence detection of the earliest transcription events in living cells is being studied by Dr W T Mason of the Biotechnology and Biological Sciences Research Council (BBSRC)-sponsored Babraham Institute. The process by which genes are translated into living organisms underpins all life. Dr Mason will be working on a method using fluorescently-labelled chemicals to show changes occurring inside living cells in real time. The approach applies the tools of molecular biology to the problems of modern cell biology in a most direct manner. Not only could this work provide a valuable research tool, but it may also be of interest to the pharmaceutical and medical diagnostics industries.

Cancer

The MRC supports basic molecular and cellular studies on cancer, its genetic predisposition, detection and diagnosis, and measures to improve treatments, including clinical trials, complementing the work of the medical charities and the Department of Health. Injecting 'killer' genes into cancer cells is one strategy currently being looked at. Imperial Cancer Research Fund scientists have devised a gene therapy for malignant melanoma, a skin cancer. Human trials began at the Fund's Oxford Clinical Oncology Unit in 1993.

The first vaccine to protect specifically against cancer was developed by British scientists funded by the charity, Cancer Research Campaign. The result of more than 25 years' research, the vaccine will be used to protect against the Epstein Barr virus, which is associated with a number of different cancers.

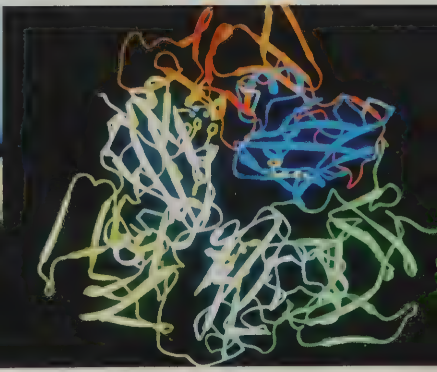
Infections and immunity

The field of immunity has seen radical advances following the application of techniques used in molecular and cell biology and protein engineering.

The BBSRC supports immunology research in animal species (for example, poultry and cattle), in certain areas of immunology (such as mucosal and developmental immunology and cytokines), and on diseases (including scrapie/Bovine

Scientists at the Imperial Cancer Research Fund are working to achieve a greater understanding of the mechanism by which cells, such as the cervical cells shown here, become cancerous.

Community doctors could soon have a new diagnostic tool at their fingertips. Sussex University's Heart Sound Group has recently developed a computerised stethoscope that analyses the digitised sound of heartbeats and conveys the data to a personal computer.



The structure of ceruloplasmin, a copper-containing blood protein, has recently been determined using the Synchrotron Radiation Source at the Daresbury Laboratory in Cheshire. Lack of this protein is thought to lead to a degenerative condition called Wilson's disease.

Spongiform Encephalopathy-type diseases, salmonella infection and exotic and bovine viruses).

The MRC plays a vital role in the international research effort to combat HIV and AIDS. Work is directed at developing antiviral drugs and vaccines, and assessing the extent of the epidemic and behavioural factors of transmission.

The Edward Jenner Institute for Vaccine Research was launched in 1994 by the MRC, BBSRC, Department of Health and Glaxo Wellcome. Situated at Compton in Berkshire, it will eventually house up to 50 researchers. Funding is provided equally by Glaxo Wellcome and the public sector participants. Its strategic research programme focuses on novel ways of improving the immune response and on new routes of delivering vaccines, providing the basis for developing new vaccines.

Neurobiology

The BBSRC finances research in behavioural and cognitive neuroscience, sensory systems and processing, sensorimotor control, neuroendocrinology, synaptic transmission and neuropathogenesis, especially prion diseases. In addition, it supports work in psychology and behaviour, including animal learning, visual processes, psychophysics and perception.

The MRC supports research to find the causes of neurological conditions (such as multiple sclerosis, stroke, head injuries and psychiatric disorders like schizophrenia) and to develop new methods for their diagnosis, prevention and treatment. Research is also concerned with, for example, discovering how hormones and other chemical messengers in the body stimulate neural responses, and how the body organises itself to repair damage. A long-term target is the stimulation of the nervous system and the brain to repair themselves even after serious damage.

Pharmaceuticals

Britain is the world's third largest exporter of medicines. In 1995 the pharmaceuticals industry, with around 20,000 employees engaged on R&D work, invested £2,000 million in R&D, representing about 10 per cent of total world spending on pharmaceuticals research.

Research conducted by Zeneca, Glaxo Wellcome, SmithKline Beecham and Fisons has led to the development of semi-synthetic penicillins and cephalosporins (both powerful antibiotics), new vaccines and new treatments for asthma, migraine, coronary heart disease and arthritis.

Glaxo Wellcome, which is the biggest pharmaceuticals company in the world, has a new £700 million research centre at Stevenage in Hertfordshire. It manufactures Zantac, the world's best-selling medicine, which is used in the treatment of gastric ulcers. Other new drugs include Zofran, an anti-nausea drug for countering the unpleasant side effects of cancer treatments, and drugs for the treatment of migraine which stimulate receptors in the brain. It is at present conducting research into drugs for controlling certain viral diseases and cancers by regulating malfunctioning genes.

Glaxo Wellcome hopes to have its own triple combination of drugs for treating AIDS on sale within the next two years. The company already has on the market two of the three components of most triple therapy regimes, AZT and 3TC. The third drug is a protease inhibitor. Although expensive, part of the cost of the drugs would be offset by not having to treat patients for complications such as tuberculosis.

British Biotech has been developing a promising anti-cancer drug called marimastat, a matrix-metalloproteinase (MMP) inhibitor. It is part of a family of enzymes involved in destroying old or damaged tissues, and is thought to stop the spread of tumours without actually killing them. If successful, the drug would allow cancer sufferers to live with cancer and it could be used in conjunction with other treatments, such as chemotherapy. One considerable advantage is that it would be taken orally.

Zoladex, a drug made by Zeneca to treat prostate cancer, is being developed to treat breast cancer and benign gynaecological disorders.

Biotechnology

Biotechnology applies the understanding of living organisms and their components in the creation of industrial products and processes. It includes the manufacture of products using genetic modification techniques, following the discovery of the structure of DNA at Cambridge University in the 1950s. It is expected to have a major impact on industrial sectors such as pharmaceuticals, healthcare, food and agriculture, as well as on advanced materials engineering plastics. Britain has made many major advances in biotechnology, including:

- the development of drugs like human insulin and interferon and genetically engineered vaccines
- production of antibiotics by fermentation
- bactericidal drugs based on Nisin, a food preservative made in Britain
- medical diagnostic meterials like biosensors
- a development of crop varieties that are resistant to infection or have improved qualities.

Britain leads in several key biotechnology areas, including the development of molecular graphics, which contribute to the rational design of new and improved medicines through a computer-aided technique for analysing the structures of complicated organic molecules.

Agriculture and food research

The government agriculture departments, the BBSRC and industry share responsibility for research. This is carried out in a network of research institutes, specialist laboratories and experimental husbandry farms, with Horticulture Research International, and in higher education institutions.

Animal science

Work on basic animal physiology and genetics at the molecular and cellular levels underpins strategic research related to animal production, health and welfare. The BBSRC, Ministry of Agriculture, Fisheries and Food (MAFF), and other organisations support genome mapping designed to allow the genetic identification of performance traits and heritable defects in farm animals. BBSRC-supported scientists are also responsible for co-ordinating an extensive European consortium which aims to produce a complete genetic map of the pig.

Animal disease research

Using modern molecular biological techniques, Research Council and MAFF scientists have devised new vaccines against animal diseases. These include:

- the Aro A live salmonella vaccine against salmonella in chickens
- the capri-pox virus vaccine containing rinderpest viral genome, which protects against

Scientists at Horticulture Research International (HRI), Britain's principal horticulture research body, based at Wellesbourne, in the Midlands, have isolated bacteria that could hold the key to a new biological system for degrading persistent organic chemicals. Here, Dr Allan Walker (foreground) examines an agar plate for bacterial growth before loading liquid samples for chromatographic analysis of herbicide residues.

A collaborative project between the Manchester Royal Infirmary and Philips, the multinational electronics company, has resulted in a pioneering X-ray system that detects brain artery aneurisms and can continuously monitor their treatment.

'Dolly' is the name given to the ewe recently produced at the Roslin Institute, Edinburgh, Scotland, from a cell taken from the mammary gland of a six-year-old sheep. Dolly is the first mammal to be cloned from an adult cell. The researchers believe that the techniques they are developing may lead to new therapies for the treatment of genetic diseases in livestock.

both lumpy skin disease and rinderpest in cattle

- a vaccine against mastitis in cattle.

Food science

The Department of Trade and Industry (DTI) has financed a national technology transfer competition to reward effective partnerships between academic researchers and industry. In 1996 it was won by the University of Manchester Institute of Science and Technology for developing Aromascan, an 'artificial nose' sensor for use in the food and drink industries. The technology has proved to be more sensitive than expert wine tasters in recognising vintages or than pigs in detecting truffles.

Plant science

Research includes the study of the genetic improvement of crops, processes affecting crop yields and soil fertility, crop nutrition and protection, managed grassland ecosystems, lower input farming systems, possible alternative crops and novel, non-food uses for crops. Significant advances have been made in the analysis of crop genomes, the study of plant reproductive processes and plant/herbivore interactions, and identifying and manipulating genes for plant products which can be used to alter pest behaviour.

Scientists from Britain, the Netherlands and France are working together to devise new technologies for improving tropical forage grasses that are naturally asexual and so cannot be improved by conventional breeding methods. This project will help farmers in the tropics to overcome problems of pest and disease attack: one type of grass covering more than 60 million hectares in South America is in danger of being wiped out by spittle bug. It will also provide opportunities for improving the agronomic traits of forage crops. Understanding the genetics of asexual seed production might allow breeders to use this phenomenon to their advantage – for example, to 'fix' hybrids in rice, maize, sorghum and millet. This research is being co-ordinated by scientists at the Institute of Grassland and Environmental Research.

Pests are a major threat to agriculture and food production in the tropics, and the problem is worsening as species become resistant to pesticides. Scientists at the University of Wales are identifying the genetic changes by which tropical pests can acquire resistance to insecticides and other pest control chemicals. The brown planthopper, for example, a serious pest of tropical rice plantations throughout the Pacific, is able to withstand a range of insecticides. Researchers are studying populations of planthopper from Sri Lanka, India, Indonesia and Australia to identify the mechanisms by which insects break down pesticides. This should suggest new strategies for preventing a build up of resistance.

Research by Dr Mike Gale of the John Innes Centre, supported by BBSRC, has revealed the striking similarity of genetic organisation across an extensive range of cereals, a finding which should accelerate progress in crop

A British company is collecting and distributing live baby eels for farming and restocking projects worldwide. The company, UK Glass Eels, takes its name from its product – eels are transparent in their early development. Here, an employee is checking the quality of the eels in one of the company's culturing units.

Scientists based at the world famous East Malling fruit tree breeding establishment in Kent, one of Horticulture Research International's sites, are using biotechnology to modify the genetic make-up of apple trees. The aim of the research programme is to show that bacteria can be used to introduce genes for disease and pest resistance into cells from apple tree leaves, which are then grown on artifical media.

improvement. Dr Gale has pioneered studies to compare the relative positions of corresponding genes in the chromosomes of species which today seem quite distinct – for example, in wheat, rice, sorghum, rye, barley and maize. At first glance, there appears to be little genetic similarity. Barley, for example, contains more genetic material than rice but fewer chromosomes. However, Dr Gale and his colleagues have found that these cereals have remarkably similar genes that are arranged in virtually identical patterns on the chromosomes.

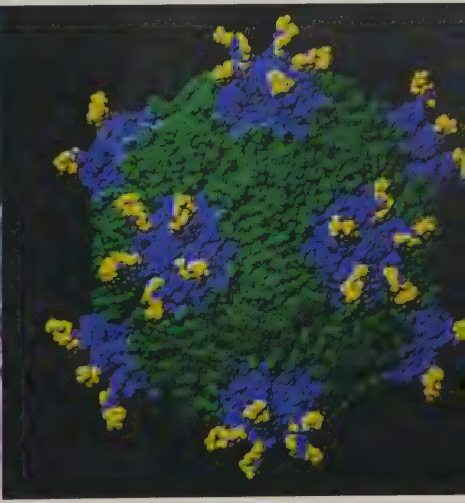
The phenomenon of gene co-linearity (synteny) allows researchers and plant breeders working with different species to pool information about individual genes, including characteristics such as disease resistance and stress tolerance which have enormous commercial importance. The location of a specific gene in the relatively simple genome of rice indicates, for instance, where the corresponding gene will be found in more complex genomes such as that of wheat.

Other chemical sectors

A large proportion of the world's R&D in agrochemicals is conducted in Britain. ICI is at the forefront of global efforts to develop substitutes for chlorofluorocarbons (CFCs); in 1991 in Runcorn, Cheshire, it opened the world's first plant to manufacture HFC 134a, a less damaging alternative to CFC.

Notable British agrochemical discoveries include synthetic pyrethroid insecticides, systemic fungicides and aphicides and methods of encouraging natural parasites to attack common pests in horticulture. In fibres, Courtaulds has invented a new solvent-spun, biodegradable fibre, Tencel, which is twice as strong as cotton but soft enough to be used in luxury garments.

In a BBSRC project, scientists at the Institute of Arable Crops Research, at Rothamsted, southern England, are using a combination of molecular biology, radar and mathematical computing to gather information that will help control insect pests and conserve beneficial species. Pictured here is a bee to which a radar tracking system weighing only 3 milligrams has been attached.



This computer model, produced by scientists at the John Innes Centre, near Norwich, shows protein molecules (blue and green) coating a plant virus, to which fragments (yellow) of an animal virus, such as foot-and-mouth or HIV, have been attached by genetic engineering. This hybrid virus particle can be used to stimulate the immune system to make antibodies against the disease-causing organism.

Environmental and earth sciences

A multi-disciplinary team of scientists, mathematicians and engineers at HR Wallingford, the hydraulics research centre near Oxford, southern England, is studying the management of water resources. A scientist is seen here using a physical model to simulate the effects of wave movements on a beach.

Scientists and engineers at the Southampton Oceanography Centre have collaborated to create the first autonomous underwater vehicle – Autosub. Following successful trials off the south coast of England in 1996, Autosub undertook its first full-scale data collection mission in Scottish coastal waters in the spring of 1997.

Introduction

Growing pressures for higher environmental standards and the need to halt degradation of the environment have resulted in greater emphasis on environmental research. While it plays a part in the work of all the Research Councils, the lead agency is the Natural Environment Research Council (NERC), much of whose work is done in collaboration with major international programmes. British scientists have a crucial role in research on assessing and repairing environmental harm caused by pollution. There is a substantial R&D effort, supported by the Government, to improve the technology of pollution control. The Government has also launched a new Environmental Technology Best Practice Programme, which informs business about cost-effective reduction of pollution and waste.

Earth observation (see p. 23) makes a vital contribution to many environmental programmes, both national and international, concerned with geology, land use, pollution control, weather and climate studies.

Global environment

Using models generated by computers, climatologists can predict how a gas introduced into the atmosphere at one point is distributed in varying amounts around the globe. The NERC supports a consortium of five universities on a project to model the atmosphere using computers. This programme concentrates on the natural variability of the atmosphere and its response to 'greenhouse forcing', and the dynamics and prediction of ozone depletion.

The Terrestrial Initiative in Global Environment Research (TIGER), started in 1991, is the largest study of the natural environment undertaken in Britain and will make a significant contribution to global change projects. It focuses on the response of nature to effects such as global warming and stratospheric ozone-depletion at sites in Britain and the tropics. TIGER's two research sites in Britain are complemented by others in Amazonia, Africa and Canada. Data from experiments on energy/water balance carried out in the Amazonian rainforest are now being used in global climate models.

The NERC carries out strategic surveys of Britain's land mass and offshore regions, which give essential information on mineral resources, water resources, environmental protection, natural hazards and land use. A comprehensive geological survey of Britain's inner continental shelf, completed by the British Geological Survey, has yielded a detailed picture of its margin and associated natural resources. A 15-year programme of onshore re-survey was begun in 1991 and has already revealed a new phase of mineral deposits in Cornwall. The NERC's Offshore Survey and Geophysical Monitoring project investigates the mineral resources and seismic hazards of Britain's offshore areas.

Britain participates in the Ocean Drilling Program (ODP), the world's largest and most successful international scientific research project in the earth sciences. Current studies include those on the geology of ocean basins, mid-ocean ridges, marine sedimentation and ocean circulation.

Marine sciences

The NERC's Land Ocean Interaction Study (LOIS) is a major project to study the dynamics of coastal environments and the flow of materials into and across the coastal zone from the air, the land and rivers and the sea.

It will provide the basis for predictions of the impact on the coasts of future natural and man-made changes.

Polar sciences

The British Antarctic Survey (BAS), one of the NERC's research institutes, has been undertaking research in Antarctica for many decades. It has five permanent research stations there, carrying out continuous research and monitoring. BAS collaborates with 21 other countries as part of the Antarctic Treaty, and its research covers: climate change, notably the depletion of the ozone layer over the Antarctic; global warming; past climate patterns (through ice-core analysis); oceanographic processes; and geospace observations.

Conservation

As part of its response to the 'Earth Summit' at Rio de Janeiro in 1992, the Government published a Biodiversity Action Plan in 1994 outlining Britain's role in conserving biological diversity at home and overseas.

Darwin Initiative

The Darwin Initiative for the Survival of the Species aims to deploy Britain's scientific, educational and technical strengths to assist the conservation of the world's species. It covers five project areas: collaborative research; help to Eastern Europe and the former Soviet Union; training courses; neglected areas of research; and work related directly to the Biodiversity Convention.

Presently, there are 116 projects involving 70 institutions in Britain and collaborative links with almost 60 countries. The majority of new projects are in Africa, South America and South East Asia, and will all be directed by British educational and scientific bodies, including the Natural History Museum, Zoological Society of London, Raleigh International, Birdlife International, Royal Botanic Gardens, Earthwatch, Plymouth Marine Laboratory and ten universities.

Identifying and monitoring biodiversity are essential to inform action to conserve biodiversity. The Institute of Terrestrial Ecology has collaborated with the National Biodiversity Data Bank in Kampala to produce an inventory of species in the Sango Bay wetland in Uganda. This has been achieved through a combination of extensive fieldwork, use of satellite images and a geographical information system. A new project by the University of Warwick will assess the sustainability of the wildlife and rattan trades in North Sulawesi in Indonesia.

Screening and evaluating genetic diversity

A project, funded by the European Community Biotechnology Programme, to develop universally useful molecular tools for screening and evaluating the planet's genetic diversity has begun to identify the most appropriate techniques and strategies. It involves 35 research groups, including four industrial partners (among them Zeneca), in 12 European countries, co-ordinated by Dr Angela Karp of the Institute of Arable Crops Research (IACR)-Long Ashton Research Station.

An important finding is that some 'genetic fingerprinting' techniques have limited suitability for wide-scale screening because they are not reproducible enough between laboratories. A second important result is that decisions to conserve something cannot be made solely on differences in the level of biodiversity. Information on evolutionary history (phylogenies) is critical for providing a framework of understanding of the significance of genetic diversity studies. Phylogenetic relationships reveal how long it has taken for species to evolve and is important data for conservation, which can provide insights into the history of populations and their differentiation over space and time.

A Darwin Initiative-funded project based in Peru is looking at the genetics of llamas, whose wool forms a crucial part of the country's economy. Dr Helen Stanley, who works at the Zoological Society of London, and Dr Jane Wheeler, one of her collaborators in Peru, are investigating whether the way in which the animals are managed affects their genetics.

The Coastal Biodiversity Research Group from NERC's Plymouth Marine Laboratory, headed by Dr Richard Warwick, has recently won funding from the Darwin Initiative for projects on marine biodiversity in Thailand. Here, pond-cultured fish are being air-dried prior to storage or transportation.

The Millennium Seed Bank has been established at the Royal Botanic Gardens at Kew, London. This Darwin Initiative-funded project will store and make available to researchers worldwide genetic material from the largest collection of botanic specimens held anywhere.

Conservation within natural habitats

Considerable research and management are carried out to encourage the recovery of populations of species threatened with extinction. For instance, improvement in the quality of river water, a ban on the use of pesticides such as DDT and a ban on otter hunting have enabled otters to spread from existing populations in Britain.

Conservation outside natural habitats

Historically, Britain has played a major role in the development of techniques for conserving species away from their natural habitats *(ex situ)*. Several institutions are internationally recognised as world leaders, among them the Royal Botanic Gardens, which has been at the forefront of botanical research and plant conservation for 200 years. Kew houses the largest and most diverse collection of living plants, and the most comprehensive collection of dried plants in the world. Research is conducted into all aspects of plant life, including physiology, biochemistry, genetics, economic botany and the conservation of habitats and species. It is active in programmes to return endangered plant species to the wild. Kew participates in joint research projects in more than 50 countries.

Today, as natural plant habitats throughout the world are being destroyed and plants are becoming extinct, a priority of the research at Kew is to assess the value of whatever is being lost, so that a way can be found to reduce and reverse the rate of destruction of species.

A national botanic garden and research centre for Wales is to be developed on a 230-hectare site at Llandeilo, near Swansea. The £43 million project is backed by a consortium of public and private organisations and individuals. It has been awarded £22 million by the Millennium Commission.

Many micro-organisms, including viruses, bacteria, protozoa and most algae and fungi, are conserved in culture collections. These collections have a research and applied value, particularly in industry – for example the National Collection of Industrial and Marine Bacteria (for industrially significant bacteria). Research is carried out at British microbiological institutes to enhance preparation techniques and long-term storage methods – especially with liquid nitrogen. New protocols for preservation are being developed using cryogenic stage microscopy, enabling some species to be preserved satisfactorily for the first time.

Many zoos in Britain play a vital role in programmes for reintroducing species of international importance. Some have a wider role providing management plans for areas and species of conservation interest. London Zoo, for example, is involved in 92 nationally and internationally co-ordinated captive breeding programmes for exotic species and manages 22 such programmes.

Urban environments

Urban Regeneration and the Environment (URGENT)

URGENT is a NERC programme designed to help solve problems of the urban environment caused by rapid industrialisation and urbanisation, which threaten ecosystems and the health of inhabitants, inhibit redevelopment and diminish the quality of life. The aim is to: improve air, soil and water quality; tackle the problem of contaminated land; reduce physical hazards; and manage natural resources and urban ecosystems sensitively. Research focuses on understanding patterns and processes in the shallow sub-surface, atmosphere dynamics and chemistry, hydrological balances and urban ecology.

Energy research

Clean power generation is an important issue for industrialised nations and for the developing world. There is particular concern about levels of nitrogen oxides in the atmosphere and rates of carbon dioxide (CO_2) emission. Projects are under way for developing cleaner and more efficient power generation from renewable or widely available, long-lived fuel sources such as coal.

The Government supports an R&D programme into

Right: The world's biggest flue gas desulphurisation plant, and Britain's largest environmental protection project, has been completed at Drax Power Station in Yorkshire, northern England. The purpose of the plant is to remove more than 90 per cent of the sulphur dioxide from the Drax chimney gases.

Left: One of five wind turbines, the largest of which is 17 metres in diameter, currently being evaluated at the Wind Turbine Test Site by the Energy Research Unit, a division of the Rutherford Appleton Laboratory.

efficient power generation from renewable or widely available, long-lived fuel sources such as coal.

The Government supports an R&D programme into renewable forms of energy, which concentrates resources on key technologies – energy from coppice and waste, wind, solar and fuel cells – and aims to increase their appeal to investors.

The main mechanism for encouraging the commercial uptake of renewables is the Non-Fossil Fuel Obligation (NFFO). This is a competitive scheme, whereby producers of electricity who are awarded contracts receive premium price payments for electricity produced from renewable sources. A total of 476 MW of renewables capacity produced from NFFO (and similar arrangements in Scotland and Northern Ireland) was 'on stream' at the end of June 1997, from 210 projects.

Under the OST's Foresight Initiative, photovoltaics was identified as one of the technologies requiring priority attention. One of the successful Foresight Challenge awards was to set up PV demonstration projects in 100 schools and colleges across the country. The Energy Panel is taking forward the other top priorities for action, and assessing the second priority technologies, eg energy crops, energy from waste and fuel cells.

Britain has pioneered the most important advance in coal combustion this century – the technique of fluidised bed combustion. The technique allows a wide range of coals, including low quality coals, to be used and – with the addition of limestone or dolomite to the bed – leads to lower polluting sulphur emissions to the atmosphere.

One such advanced system is the coal topping cycle programme, in which some of the coal is converted to hot gas for use in a gas turbine and the remaining char is burnt in a fluidised bed to raise steam for a conventional steam turbine. This offers the opportunity to reduce CO_2 emissions from coal-fired power stations by 20 per cent and is being developed by an industry-led consortium.

ADDRESSES AND FURTHER READING

Government departments

Department for Education and Employment,
Sanctuary Buildings,
Great Smith Street,
London SW1P 3BT.
http://www.dfee.gov.uk

Department of the Environment, Transport and the Regions,
Eland House,
Bressenden Place,
London SW1E 5DU.
http://www.detr.gov.uk

Department of Health,
Richmond House, 79 Whitehall,
London SW1A 2NS.
http://www.open.gov.uk/doh/dhhome.htm

Department for International Development,
94 Victoria Street,
London SW1E 5JL.
http://www.oneworld.org/dfid/

Department of Trade and Industry,
1 Victoria Street,
London SW1H 0ET.
http://www.dti.gov.uk/

Foreign & Commonwealth Office,
King Charles Street,
London SW1A 2AH.
http://www.fco.gov.uk/

Ministry of Agriculture, Fisheries and Food,
3 Whitehall Place,
London SW1A 2HH.
http://www.maff.gov.uk/

Ministry of Defence,
Whitehall, London SW1A 2HB.
http://www.mod.uk/

Northern Ireland Office,
Stormont Castle,
Belfast BT4 3ST.
http://www.nio.gov.uk/

Office for National Statistics,
1 Drummond Gate,
London SW1V 2QQ.
http://www.ons.gov.uk/

Office of Science and Technology (DTI),
Albany House, 94–98 Petty France,
London SW1H 9ST.
http://www.dti.gov.uk/ost/

Scottish Office,
St Andrew's House,
Edinburgh EH1 3DG.
http://www.open.gov.uk/scotoff/scofhom.htm

Welsh Office,
Cathays Park, Cardiff CF1 3NQ.
http://www.cymru.gov.uk/

Research Councils

Biotechnology and Biological Sciences Research Council,
Polaris House,
North Star Avenue,
Swindon, Wiltshire SN2 1UH.
http://www.bbsrc.ac.uk/

Council for the Central Laboratory of the Research Councils,
Rutherford Appleton Laboratory,
Chilton, Didcot,
Oxfordshire OX11 0QX.
http://www.cclrc.ac.uk/

Economic and Social Research Council,
Polaris House,
North Star Avenue, Swindon,
Wiltshire SN2 1UJ.
http://www.esrc.ac.uk/

Engineering and Physical Sciences Research Council,
Polaris House,
North Star Avenue, Swindon,
Wiltshire SN2 2ET.
http://www.epsrc.ac.uk/

Medical Research Council,
20 Park Crescent,
London WIN 4AL.
http://www.mrc.ac.uk/

Natural Environment Research Council,
Polaris House,
North Star Avenue, Swindon,
Wiltshire SN2 1EU.
http://www.nerc.ac.uk/

Particle Physics and Astronomy Research Council,
Polaris House,
North Star Avenue, Swindon,
Wiltshire SN2 1SZ.
http://www.pparc.ac.uk/

Others

Committee of Vice-Chancellors and Principals of the Universities of the United Kingdom,
Woburn House,
20 Tavistock Square,
London WC1H 9HQ.
http://www.cvcp.ac.uk/

Royal Academy of Engineering,
Gaywood House,
Great Peter Street,
London SW1P 3LW.
No site yet

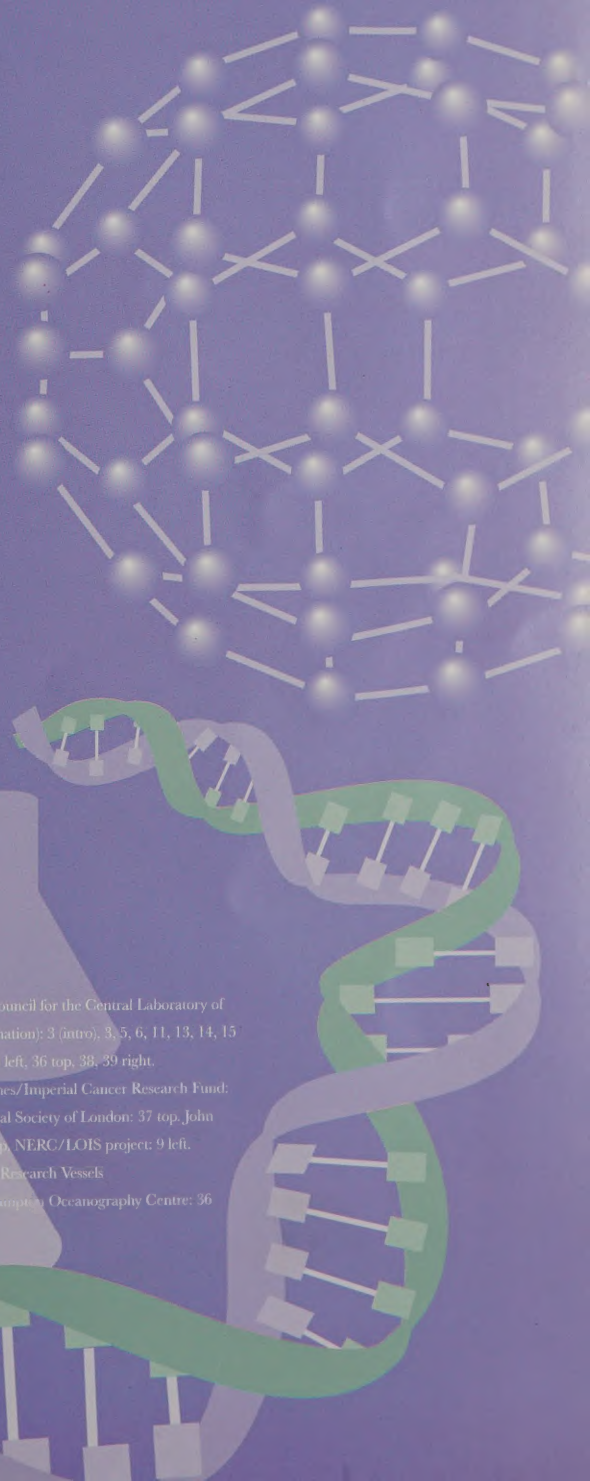
Royal Society,
6 Carlton House Terrace,
London SW1Y 5AG.
http://www.royalsoc.ac.uk/

The British Council,
Bridgewater House
58 Whitworth Street,
Manchester M1 6BB.
http://www.britcoun.org/

The Office of Science and Technology publishes a large variety of publications on science, engineering and technology issues, as does the British Council. Each Research Council issues an annual report and various other publications describing their work. The Office for National Statistics publishes a series of Business Monitors and media releases providing details of total R&D expenditure. All these publications are available from the addresses given.

Abbreviations

AIDS	Acquired Immune Deficiency Syndrome
BAS	British Antarctic Survey
BBSRC	Biotechnology and Biological Sciences Research Council
BNSC	British National Space Centre
BT	British Telecom
CASE	Co-operative Awards in Science and Engineering
CCLRC	Council for the Central Laboratory of the Research Councils
CERN	European Laboratory for Particle Physics
CFCs	Chlorofluorocarbons
COPUS	Committee on the Public Understanding of Science
DERA	Defence Evaluation and Research Agency
DFID	Department for International Development
DNA	deoxyribonucleic acid
DTI	Department of Trade and Industry
EMBL	European Molecular Biology Laboratory
EPSRC	Engineering and Physical Sciences Research Council
ERS	European Remote Sensing
ESA	European Space Agency
ESRC	Economic and Social Research Council
EU	European Union
EUREKA	European High Technology Programme
GDP	Gross Domestic Product
HERA	Hadron Electron Ring Accelerator
HGAC	Human Genetics Advisory Commission
HIV	Human Immunodeficiency Virus
IACR	Institute of Arable Crops Research
IRC	Interdisciplinary Research Centre
LEP	Large Electron Positron Collider
LHC	Large Hadron Collider
MAFF	Ministry of Agriculture, Fisheries and Food
MERLIN	Multi-Element Radio Linked Interferometer Network
MRC	Medical Research Council
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organisation
NERC	Natural Environment Research Council
NIR	Near Infra-red
OECD	Organisation for Economic Co-operation and Development
OST	Office of Science and Technology
PPARC	Particle Physics and Astronomy Research Council
PTP	Postgraduate Training Partnerships
R&D	Research and Development
ROPA	Realising Our Potential Award
RTOs	Research and Technology Organisations
SuperJANET	Super Joint Academic Network
TCS	Teaching Company Scheme
TIGER	Terrestrial Initiative in Global Environment Research



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